Yüksek Sıvı Basınç (YSB) Uygulamasının Su Ürünlerinin Kalite Parametreleri ve Raf Ömrü Üzerine Etkisi

Proje No: 108O668

Prof.Dr. Hami ALPAS
Doç.Dr. Nuray ERKAN ÖZDEN

MART 2011
ANKARA

ÖNSÖZ

TÜBİTAK-1001 Bilimsel ve Teknolojik Araştırma Projelerini Destek Programı kapsamında 01/03/2009 – 01/03/2011 tarihleri arasında ODTÜ Gıda Mühendisliği ve İstanbul Üniversitesi Su Ürünleri Fak. Avlama ve İşleme Teknolojisi Bölümleri arasında tamamlanan 108O668 nolu projede Yüksek Hidrostatik Basınç (YSB) Uygulamasının Su Ürünlerinin Kalite Parametreleri ve Raf Ömrü Üzerine etkileri çalışılmıştır.

TEŞEKKÜR

Proje ekibi olarak TÜBİTAK-TOVAG tarafından sağlanan desteğe teşekkür ederiz.

Proje sürecinde değerli katkılarını aldığımız proje izleyici(leri)mize teşekkür ederiz.

PROJE GRUBU

Proje yürütücüsü: Prof.Dr.Hami Alpas

Araştırmacı: Doç.Dr.Nuray Erkan Özden

İÇİNDEKİLER

Tablo ve şekil listeleri

Tablolar

Şekiller

Özet

Bu projede farklı yapıdaki balıklar (dumanlanmış somon, tekir, alabalık ve istavrit) için en uygun yüksek hidrostatik basınç şartlarının önemli kalite parametrelerindeki (TMA,TBA, renk, TVB-N, mikrobiyolojik ve duyusal özellikler) değişimler ışığında belirlenmesi ve elde edilen en iyi basınç-sıcaklık-zaman uygulamalarının soğukta depolanan taze ve işlenmiş balığın kalite parametreleri ve raf ömrüne etkisinin incelenmesi amaçlanmıştır. Ayrıca alabalık ve istavrit için serbest amino aist miktarlarındaki değişimler de takip edilmiştir. En uygun YHB koşulları sırasıyla: soğuk dumanlanmış somon için 3ºC/5dk/250 MPa ve 250 MPa25ºC/10 dk; tekir için 330 MPa/3ºC/5dk ve 250 MPa/25ºC/5dk; alabalık için 220/7-15-25'^{o}C/10dk ve 250MPa/7 ve 15°C/ 5 dk olarak belirlenmiştir. Bu koşullarda seçilen YSB uygulamasının soğukta depolanan taze ve işlenmiş: somonda (2ºC) ilave olarak 2 haftalık; tekirde (4ºC) düşük YSB'de ilave 2 gün (toplamda 2 hafta), yüksek YSB'de ilave 3 gün (toplamda 15 gün) raf ömrü artışı sağladığı belirlenmiştir. Alabalıkda ise 330 MPa üzeri YSB uygulamasının uygun olmadığı ve 7 ve 15°C'lerde artan basınçla ve tutma zamanıyla serbest amino asit miktarındaki değişimlerin arttığı ancak bu değişimlerin 25°C'de yavaşladığı gözlenmiştir. İstavritde ise YSB uygulanmış örneklerde önemli ($p<0.05$) serbest amino asit değişimleri-kontrole göre- tesbit edilmiştir. Bu değişimler balığın aroma ve tadında değişimlere yolaçabileceği gibi, saklama sırasındaki kalite parametrelerini de etkileyebilmektedir. Çakışmada özetlenen sonuçların YSB'li ürünler üretmek için deniz ürünleri endüstrisine ideal bir referans oluşturacağı düşünülmektedir.

Anahtar Kelimeler: Yüksek sıvı basınç (YSB), dumanlanmış somon, tekir, alabalik, istavrit, raf ömrü, kalite parametreleri

Abstract

Different fish (smoked salmon, red mullet, rainbow trout and horse mackarel) are treated under High Hydrostatic Pressure with respect to changes in quality paramters such as TMA, TBA, color, TVB-N, microbial and sensory properties so as to determine the best pressure-temperature-time combination to be used in shelf life studies during cold storage. The resutls are compared with fresh untreated samples. In addition the changes in free amino asid content of rainbow trout and horse mackarel are also reported. The best HHP combinations determined are 3ºC/5min/250 MPa and 250 MPa/25ºC/10 min for smoked salmon; 330 MPa/3ºC/5min and 250 MPa/25ºC/5min for red mullet and 220/7-15-25'^{o}C/10min and 250MPa/7 ve 15°C/ 5 min for rainbow trout.. The fish treated for shelf life extension at the above mentioned conditions enabled an extension of additional 2 weeks of storage at 2ºC for smoked salmon; 2 (total 2 weeks) and 3 (total 15 days) days at 4ºC under relatively low and high HHP in red mullet; respectively. HHP applications above 330 MPa are found to be inappropriate for rainbow trout and also the changes in amino asid content slowed down as the pressurization temperature is raised from 7 to 15 to 25ºC. The changes in free amino asid content in horse mackarel was found to be sgnificant ($p<0.05$) with respect to control samples. These changes was suggested not only possibly affect the aroma and taste of the fish but also responsible from the quality paramter changes during storage. The results presented here are proposed to be a good starting reference for seafood industry to produce HHP treated seafoods.

Keywords: High hydrostatic pressure (HHP), smoked salmon, red mullet, rainbow trout, horse mackarel, quality parameters

1. Giriş:

Su ürünleri genel olarak beslenme fizyolojisi açısından çok değerli ancak kolay bozulabilen sınırlı raf ömrüne sahip gıda maddeleridir. Balık, kabuklu ve yumuşakçalar yüksek su aktivitesi ve nötrala yakın pH değerine sahip gıdalardır. İstenmeyen koku, tat ve görünümün ortaya çıkmasında etkin olan otolitik enzimlerin varlığı nedeniyle bu ürünler kısa sürede bozulur. Su ürünleri insan sağlığı açısından büyük önem taşımakla beraber çok sınırlı raf ömrüne sahip, kimyasal ve mikrobiyolojik bozulmanın hızlı seyrettiği hassas gıda maddelerindendir (Ludorff ve Meyer, 1973; Gram ve Huss, 2000). Soğukta depolanan balıkların kalite kayıplarında mikrobiyal aktivite genellikle baskın olup, bazı balık türleri içinde oksidatif aktivite de önemli rol oynamaktadır. Yüksek protein içeriği, esansiyel amino asitleri, doymamış yağ asitlerini içermesi ve zengin vitamin, mineral içeriği ile su ürünleri sağlıklı ve dengeli beslenmede dikkat çeken bir gıda grubunu oluşturmaktadır. Eksik ve yetersiz gıda güvenliği ile kontamine olmuş su ürünlerindeki enfeksiyon ve entoksikasyon etkenleri de tüketici sağlığını tehdit eden bir başka faktördür. (Varlık ve diğ. 2004).

Kısa süreli raf ömrüne sahip olma önemli ekonomik kayıpları beraberinde getirmektedir. Taze tüketimi tercih eden tüketiciye sağlıklı ve daha uzun dayanım ömrüne sahip ürün sunabilmek için sıklıkla tercih edilen yol soğukta buz içinde muhafazadır. Bu şekilde muhafaza edilen balık ve balık ürünlerinin dayanım ömrü türe, muhafaza sıcaklığına bağlı olarak değişmekle birlikte oldukça kısadır (Tülsner, 1994; Erkan, 2003a). Bozulma çoğunlukla sıcaklığa bağlı olup ancak düşük depolama sıcaklıklarının kullanımı ile engellenebilmektedir. Gerek raf ömrünü uzatmak, gerekse de kaliteyi artırmak ve insan sağlığı açısından daha güvenli gıdalar üretmek için yeni teknikler geliştirilmektedir. En çok tercih edilen sistem(ler) soğutma sistemleri olsa da bununla kombineli kullanılan kimyasal katkı maddelerinin kullanımı ve yeni ambalaj teknikleri yeni kullanım alanları bulmaktadır (Metin ve diğ. 2001; Erkan, 2003b; Erkan ve diğ. 2006a).

Kimyasal katkı maddeleri ile veya ısıl işlem görmüş ürünler görünüş, tat vb. özellikler bakımından doğalından farklılıklar gösterebileceği gibi, kullanılan maddelerin kanserojenik, toksijenik olduğu fikri tüketiciyi rahatsız etmektedir. Ürünlerin yapısını ve doğal özelliklerini bozmayacak onunla uyum gösterecek ve istenen güvenilir ve uzun dayanımlılık gibi etkilere cevap verecek doğal teknolojiler üretici ve tüketici tarafından tercih edilir olmaya başlamıştır.

Gıda muhafazası, gıda maddelerinin mikrobiyal bozulmalara karşı korunması veya gıda güvenliğini tehdit edici unsurlara karşı korunması için yapılan sürekli bir mücadeledir. Daha besleyici, yüksek duyusal kalitede daha taze gıda ürünlerine artan müşteri talebinin karşılanması ve kabul edilebilir bir raf ömrü elde edebilmek için yapılan çalışmalar, son on yıllık dönemde, özellikle ısıl işlem içermeyen (non-thermal) inaktivasyon teknikleri üzerine yoğunlaşmıştır. Bu yeni teknikler arasında Yüksek sıvı basınç (YSB) uygulamaları her geçen gün önem kazanmaktadır. YSB uygulaması gıdaları oda sıcaklığında işleme ve koruma metotlarının en önemlilerinden biridir ve gıda maddeleri üretim süreçlerinde mikroorganizma inaktivasyonu için kullanılan sıcaklık uygulamaları yerine kullanılması açısından da büyük önem taşımaktadır. Yüksek basınç prosesleri 100 – 1000 MPa arası izostatik basınç uygulamasını içerir. Teknik, “Le Chatelier ve izostatik kurallar” prensiplerine dayanır. Bundan dolayı yüksek hidrostatik basınç, gıdanın şekli ve büyüklüğünden bağımsız olarak tüm noktalara eşit olarak iletilir. Basınç, gıda maddesinin her noktasında eşit olduğu için, ısıl işlemde olduğu gibi madde ekseni boyunca sıcaklık değişiminden kaynaklanan farklılıklar görülmez. YSB oda sıcaklığı ve bu sıcaklığa yakın sıcaklıklarda uygulandığı için, ürünün duyusal özelliklerinde değişimlere yol açmadan, vitaminleri etkilemeden, enzim ve mikroorganizma inaktivasyonu sağlanır. YSB uygulaması 1000 MPa’ya kadar gıdalarda kovalent bağları etkilemez, sekonder ve tersiyer yapıya etki eder, zayıf hidrojen bağları ve hidrofobik bağlar geri dönüşümsüz olarak değişime uğrar. Bu durum ve uygulamanın ekonomikliğini ön plana çıkarmak için geçmiş yıllarda 100-1000 MPa basınç uygulaması çalışılmışsa da bu çalışmalar çok yüksek basınç uygulamalarının etkin ve ekonomik olmadığını ortaya koymuştur (özellikle 500 MPa ve üstü). Son yıllardaki çalışmalar maksimum 400 MPa’ya kadar basınç uygulamasının yeterli ve olumlu olacağı sonuçlarını vermiştir (Alpas ve diğ. 2003; Buzrul ve diğ. 2009).

Uzun zamandır üzerinde çalışılan ve gıda sanayi yanında bir çok alana da fayda sağlayabilecek YSB sistemi gıdalarda yapı ve besi öğelerinde değişiklik yapmadan (1000 MPa’ya kadar kovalent bağlar zarar görmemektedir) gıda maddelerinde bulunan patojen ve bozulmaya sebep olabilecek mikroorganizmaları (bir kısım enzimleride) pastörizasyon sıcaklığının çok altında sıcaklıklarda ve çok daha kısa sürelerde yüksek basınç ile inaktive etme özelliği nedeni ile birçok ülkede (ABD, Japonya, İspanya, Fransa, Çek Cumhuriyeti, Almanya, İngiltere) ürünler (deniz ürünleri, meyve suyu, et ürünleri, salam, sosis, peynir, yogurt, süt ürünleri, reçel, şekerlemeler, cips sosları, meyve preparatları vb.) geliştirilmiş ve tüketicilerin beğenisine sunulmuştur (Eisenbrand, 2005). Japonya'da son 20 yıldır diğer ülkelerde de son 10 yıldır tüketicilerin beğenisine sunulan bu ürünler diğer geleneksel yöntemlerle üretilen ürünlere göre tüketiciler tarafından artan bir oranda kabul ve rağbet görmüştür. Hatta son yapılan çalışmalarda (Cardello ve diğ. 2007; Norton ve Sun, 2008; Olsen ve diğ. 2010) YSB ile üretilen ürünlerin tüketiciler tarafından algılanan kabul riskinin diğer geleneksel (pastörizasyon, minimal işleme teknikleri, irradyasyon) ve yeni üretim teknikleri (vurgulu elektrik alanı, iyonizasyon enerjisi) ile kıyaslandığında en az olduğunu göstermiştir. Yapılan çalışmalar su ürünlerinde, ürünlerin dış ülkelere ihracatında (İtalya, Yunanistan, İspanya, Almanya vb) dondurularak saklama (-34^{o}C) ve soğuk zincirde göndermek yerine YSB sonrası sadece soğuk zincir (2 - 4 ^{o}C) ile ihracatının yeterli olacağını ve üreticiye önemli bir miktarda ekonomik katkı yapabileceğini, özellikle YSB işleminde kullanılan sıcaklığın pastörizasyon sıcaklığına kıyasla çok düşük olması nedeniyle tad değişimin olmaması, besin değerinin korunması ve ısıl işlemlerde karşılaşılan ürün kalitesinin değişimini önleyeceği için daha yüksek kaliteli ve katma değeri daha fazla olan ürünlerin eldesini sağlayabileceğini (teorik bazda) göstermiştir (Büyükcan ve diğ. 2009).

Dünyada su ürünleri alanında yüksek basınç sistemlerinin kullanılmasına yönelik çalışmalar incelendiğinde, bu sistemin taze su ürünlerinde, balık kıyması, surimi, kabuklu deniz ürünleri, deniz kestanesi, marine ve dumanlanmış ürünler gibi farklı ürünlerde kullanım alanı bulabileceği görülmektedir. Pek çok dünya ülkesinde ticari anlamda da uygulabilirliği mevcuttur. Ancak bu uygulamanın çeşitli su ürünlerinde farklı süre, sıcaklık ve basınçta bu teknolojinin denenmesine yönelik çalışmalar bulunmakla birlikte (Hurtado ve diğ. 2001a; He ve diğ. 2002), son birkaç yıl içinde diğer muhafaza yöntemleriyle kombineli olarak yüksek hidrostatik basınç uygulamasının etkilerini inceleyen literatür bildirimleri de mevcuttur (Cruz-Romero ve diğ. 2008a).

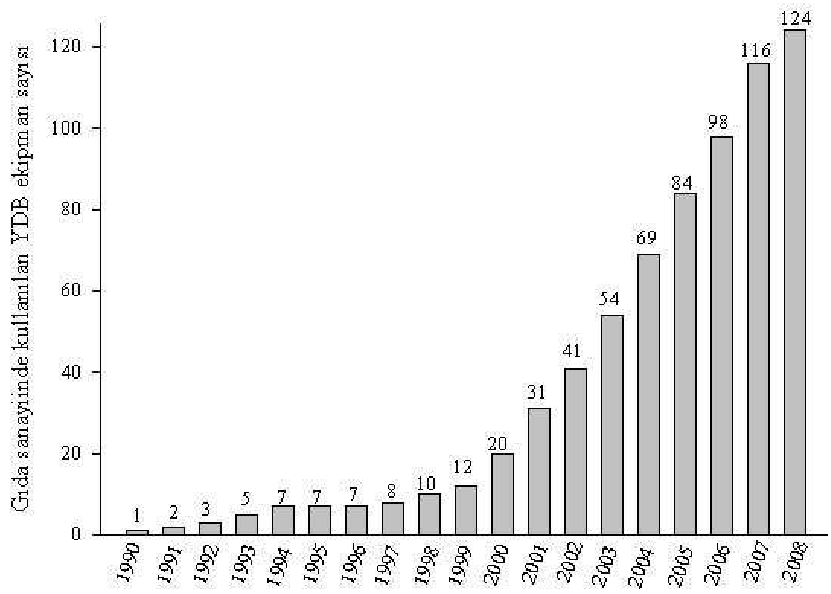
Bu çalışmada dünya literatürlerinde yüksek hidrostatik basınç teknolojisinin su ürünlerinden, özellikle taze ve işlenmiş balıklara uygulanması konusundaki literatürlerin azlığı, ülkemizde ise taze balığa YSB uygulanması konusunda hiç çalışma yapılmamış olması göz önüne alınarak; farklı yapıdaki balıklar için en uygun yüksek hidrostatik basınç şartlarının belirlenmesi ve bu uygulamanın soğukta depolanan (4-12ºC) taze ve işlenmiş balığın kalite parametreleri ve raf ömrüne etkisinin incelenmesi amaçlanmıştır.

2. Genel Bilgiler:

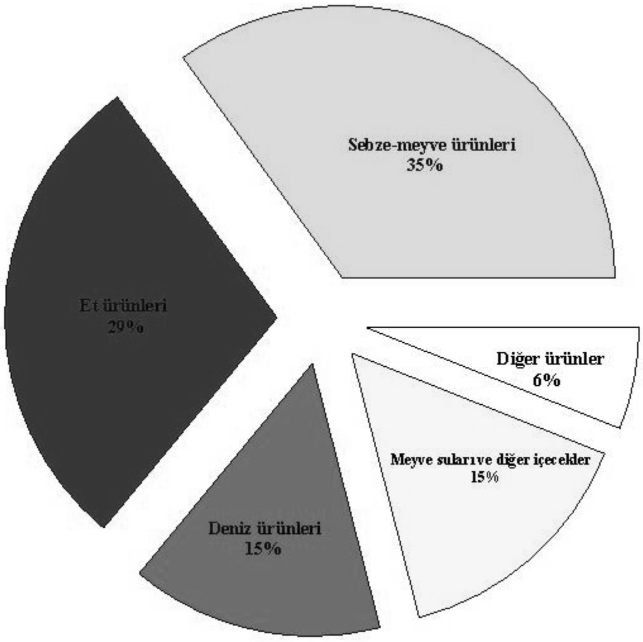
Günümüzde sağlığına ve doğal beslenmeye dikkat eden tüketici gruplarının hızla arttığı ve buna bağlı olarak güvenli gıda üretimi ve tüketicilere sunulmasının önemi kristal bir gerçektir. Gıda endüstrisinde YSB uygulaması sadece gıdaların raf ömrünün artırılması amacıyla değil, aynı zamanda daha güvenli, daha uygun, besisel ve duyusal açıdan daha kaliteli gıdaların üretilebilmesine olanak veren bir tekniktir. Bu yönleri ile ısıl işlem teknikleri içeren geleneksel gıda işleme yönetmelerine alternatif olabilecek kapasiteye sahiptir. Günümüzde gıdaların mikrobiyal açıdan stabil hale getirilmesinde en yaygın kullanılan yöntemler ısıl işlemlerdir. Yüksek sıcaklık uygulaması besi değerinde ciddi kayıplara neden olurken, düşük sıcaklık uygulamalarındaki şok dondurmada yüksek maliyet getirmektedir. Su ürünleri ise halkımız tarafından taze tüketim potansiyeli yüksek bir gıda grubudur. Proje önerilirken tazelik koşullarını uzun süre saklayacak bir teknoloji ile bu ürünlerin kalitesinin ve doğallığının korunmasında yüksek basınç uygulamasının etkili olacağı düşünülmekte idi. Raporda sunulan ve yayınlanan sonuçlar bu hipotezin doğruluğunu göstermketedir. Su ürünlerinde yüksek basınç uygulamasına dair dünyada çalışmalar mevcuttur; ancak halen yeterli değildir ve direk olarak ülkemize uygulanması -yeterli ve kapsamlı bilimsel ön çalışmalar tamamlanmadan- mümkün görünmemektedir. Bu çalışmada elde edilen ve özetlenen sonuçların bu soruna büyük bir çözüm ve katkı sağlayacağı düşünülmektedir.

Su ürünleri yüksek protein, zengin vitamin ve mineral kompozisyonun yanında kolay bozulabilir hassas gıdalar sınıfında yer almaktadır. İşleme ve depolama sırasında su ürünleri enzimatik, kimyasal ve mikrobiyolojik etkenlerle kısa sürede kalite kaybına uğramakta, dayanım ömürleri sınırlı kalmaktadır. Su ürünlerinin dayanım ömrünü ve kalitesini, depolama süresi ve sıcaklığı, depolama ve ambalajlama şartları, ürünün başlangıç kalitesi, mikrobiyal yükü, çevresel faktörler etkilemektedir (Huss, 1994). Balıklarda ve diğer su ürünlerinde bozulma otolizle başlar, mikrobiyal bozulmayla devam eder ve en sonunda tüketilemez hale gelir. Enzimatik ve bakteriyel bozulmanın geciktirilmesi için soğutma, dondurma, değişik ambalajlama teknikleri (vakum ambalaj, sarma ambalaj, modifiye atmosferle paketleme) (Smith ve diğ.1990; Randell ve diğ, 1997; Ordóñez ve diğ, 2000; Giménez ve diğ, 2002; Masyinom ve diğ, 2002; Erkan ve diğ. 2006a) ve kimyasal koruyucularla (Sodyum laktat, propil gallat, laktik asit, potasyum sorbat, kalsiyum laktat, sodyum sitrat, sodyum asetat) (Erkan ve diğ. 2001; Metin et al., 2001; Erkan, 2003a-b) muamele edilerek veya gamma radyasyon uygulaması yapılarak (Chouliara ve diğ. 2004; Chouliara ve diğ. 2005, Ozden ve diğ. 2007) raf ömürleri uzatılabilmekte ve kaliteleri artırılabilmektedir. Bütün gıda sanayinde ve su ürünlerinde dayanım ve kalitenin artırılmasında ayrıca gıda güvenliğinin sağlanması için yeni yöntemler geliştirilmektedir. Bazen geliştirilen yeni teknikler eskiden beri kullanılan diğer muhafaza teknikleri ile birlikte kullanılmaktadır. (Soğuk muhafaza-modifiye atmosferle paketleme veya kimyasal koruyucu – soğuk muhafaza-modifiye atmosferle paketleme, ışınlama –diğer muhafaza teknikleri gibi bu sayı artırılabilmektedir). Tüm bu işlemler yapılırken elde edilecek pozitif sonuç kadar yapılan işin maliyeti ve uygulanan işlemlerin doğala en yakın olması tercihi artırmaktadır.

YSB sistemlerinde genel olarak “doğru” kabul edilen temel “yanlışlardan” en önemlisi maliyet unsurudur. Sabit giderin diğer alternatif üretim teknolojilerine (en başta zaman-sıcaklık kombinasyonlarına) oranla yüksek olduğu doğrudur ancak değişken giderlerin (soğutma, ön ısıtma, koruma amaçlı paketleme, raf ömrü ve saklama sıcaklığı temini vb. giderler) ise YSB’de yok denecek kadar az olduğu göz önüne alınırsa sadece toplam maliyet unsurları açısından bile çok kuvvetli bir alternatif olduğu görülebilir. Durum bu olmasa idi tüm dünyada (ABD, AB ülkeleri, Avustralya, Japonya) YSB ile üretilen ürün çeşitliliği ve adedi sürekli artmazdı, bu ürünler içinde yükseklen trendi ise “taze” tüketime uygun deniz ürünleri almaktadır ve deniz ürünleriyle olan bazı uygulamalarda karlılığın artığı betimlenmektedir. Bu bağlamda tüm dünyada son yıllarda endüstri tarafından satın alınan ve üretim yapan YSB cihaz sayıları ve üretilen ürünlerin gruplanması aşağıda verilmiştir (Campus 2010) (Şekil 1 ve 2).



Şekil.2.1. Endüstriyel YSB cihaz sayıları



Şekil 2.2. YSB ile üretilen endüstriyel ürünlerin grupları

Tablo 2.1'de uygulanan basınç ve sıcaklığa bağlı olarak 1 litre suya iletilen enerjinin karşılaştırması verilmiştir. Buradan aynı enerji gereksinimiyle basınç altında daha fazla iş yapılabileceği (basınç 400 kat artarken sıcaklıkta sadece %25'lik bir artış elde edilebiliyor) ve gıda biliminde sıcaklık ve basınç fenomenlerinin tamamen farklı olduğu görülmektedir (Buzrul, 2008).

Tablo 2.1. 1 litre suyun aynı enerji değeri kullanıldığında sıcaklık ve basıncında oluşan artış

	1 litre H_2O	
Sıcaklık (*T*)	P = 0.1 MPa T = 20 → 25 ℃	E ≈ 20 kJ
Basınç (*P*)	T = 20 ℃ P = 1 MPa → 400 MPa	E ≈ 20 kJ

Yukarıda da özetlendiği gibi su ürünleri genel olarak dayanımı çok kısa olan ürün grubunu oluşturmaktadır. Yüksek sıvı basınç uygulamasının gıda korunumunda kullanılması halen-göreceli olarak- yeni bir tekniktir. Su ürünlerinde bu tekniğin denemesi de oldukça yenidir. Çalışmamıza kadar ülkemizde bu konuda yapılmış yaygın bir çalışma bulunmamakta idi. Literatürde incelenen çalışmalarda ise tekstür, renk gibi fiziksel parametreler ile pek çok kimyasal parametreye yüksek basınç işleminin farklı etkilerde bulunduğunu görülmektedir. Bir üründe olumlu yönde tespit edilen bir bulgu bir başka üründe istenmeyen sonuç olarak değerlendirilebilmektedir. Ayrıca su ürünleri başlığı altında incelenen her grup örnek aynı koşullarda saklansa bile dayanım ömrü bakımından birbirinden oldukça büyük farklılıklar göstermektedir.

Bu projede (verilen destek miktarındaki azaltmaya ve proje panel kabul raporundaki tavsiyeye bağlı olarak bazı su ürünlerinde-kabuklular,kafadan ve eklem bacaklılar- çeşit olarak azalmaya gidilmesine rağmen) ülkemizdeki pek çok su ürünü çalışılmıştır.. Her su ürünü grubu için en ideal şartların belirlenmesinin pratikteki uygulamalara büyük avantaj sağladığı görülmüştür. Konuyla ilgili iki farklı üniversiteden farklı fakültelerin bölümlerinin ortak işbirliğinin yarattığı bilimsel sinerji ve diğer ilgilenen kuruluşlarla birlikte sonuçların ticari ürüne dönüştürme aşamasının tamamlanması beklenmektedir. Aşağıda detaylandırılan sonuçlarının kullanılabilme potansiyeli hayli yüksek bulunmaktadır. Ancak yine de burada son uygulamaya geçiş kararı endüstrinindir.

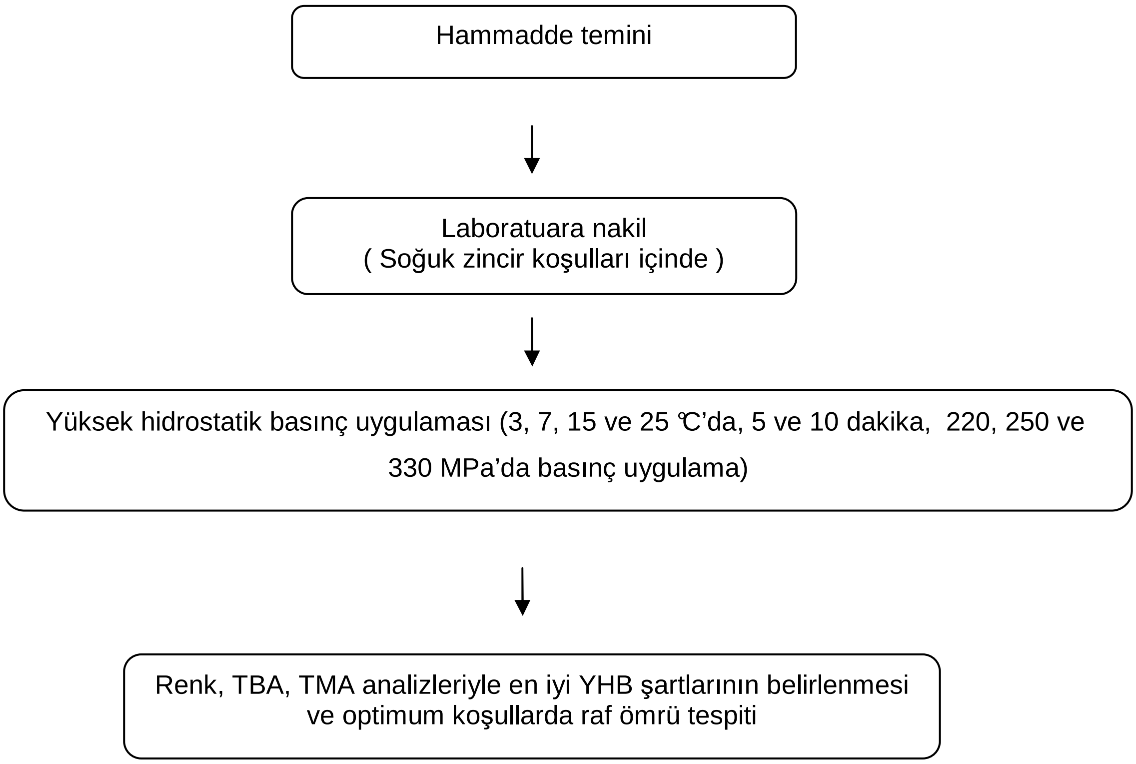
3. Gereç ve Yöntem

Çalışmada mevsimler koşullara ve taze balığın bulunduğu aylara bağlı olarak sırasıyla işlenmiş ürün olarak dumanlanmış somon, taze balık olarak tekir *(Mullus surmutelus)*, istavrit *(Trachurus trachurus)* ve proje döneminin yaz dönemine geldiği ve balık avcılık sezonunun kapalı olduğu dönemlerde taze ürün olarak alabalıkla- kültür alabalığı *(Onchorynchus mykiss)* çalışma yapılmıştır. Çalışmalarda kullanılan gereç ve yöntem sırasıyla aşağıda verilmiştir.

3.1. YSB uygulamasının dumanlanmış somonun kalite parametreleri ve raf ömrü üzerine etkisi

Dumanlanmış somon örnekleri Alarko, Kocaeli şirketinden üretimden hemen sonra temin edilmiştir, soğuk zincir şartlarına uygun olarak ODTÜ, Gıda Mühendisliği YSB laboratuvarına getirilmiştir. Balıklar, küçük porisyonlar halinde streç filmle sarılarak, Yüksek Hidrostatik Basınç cihazının haznesine yerleştirilmiştir. 3, 7, 15 ve 25℃'da 5 ve 10 dakika süre 220, 2 50 ve 330 MPa'da kombinasyonlar uygulanmış ve bu örneklerde en iyi YHB şartlarını belirleyebilmek için renk, Trimetilamin azot (TMA-N) ve Tiyobarbitürik asit sayısı (TBA) analizleri yapılmıştır (Şekil 3.1.1).

Ayrıca somon için belirlenen en iyi koşullarda 2ºC'de raf ömrü çalışması duyusal, kimyasal ve mikrobiyolojik analizler yapılarak takip edilmiş ve kontrol grubuyla karşılaştırılmıştır.



Şekil 3.1.1. Dumanlanmış somon için uygulanan çalışmanın akış şeması

Sonuçlar, paralellerin ortalaması alınarak ± standart sapma (SD) olarak verilmiştir. Çoklu karşılaştırmalar için parametrik varsayımların gerçekleştiği verilerde tek yönlü varyans analizi (ANOVA) uygulanmıştır. Bu test ile fark bulunan gruplarda, farklılığın nereden kaynaklandığını bulmak için Tukey testi kullanılmıştır. Gruplar arası ve depolamaya bağlı parametrelerde değerlendirmeler ve parametreler arası ilişki $P<0,05$ olması anlamlı kabul edilmiştir. Bu analizler İstanbul Üniversitesi Su Ürünleri Fakültesi, İşleme Teknolojisi Laboratuarlarında gerçekleştirilmiştir.

3.1.1. Renk Analizi

Her grup örnekte et üzerinden 3 noktadan renk ölçümü yapılmıştır. Hunter Lab sisteminde L^*parlaklığı (0'dan 100'e kadar derecelendirme siyahtan beyaza renk dağılımını); a^* pozitif değerdeyken kırmızı negatif değerde yeşili ve b^* pozitif değerde sarıyı negatif değerdeyken mavi renk aralığını ifade etmektedir. ΔE (renk farkı)= $(\Delta L^2+\Delta a^2+\Delta b^2)$'nin karekökünün alınması ile hesaplanmıştır (Gerdes ve Santos Valdez, 1991).

3.1.2. Trimetilamin Azot (TMA-N)

Trimetilamin azot (TMA-N) analizi AOAC (1998)' e göre yapılmıştır. Spektrofotometre olarak UV/VIS double beam spectrophotometer T80 Series (PG Instruments Ltd., Wibtoft. Leics. İngiltere) kullanılmıştır.

TMA değeri (mg/100 g balık eti): Standart eğriden okunan TMA değeri x dilüsyon faktörü/ örnek ağırlığı

3.1.3. Tiyobarbitürik Asit Sayısı Tayini (TBA)

TBA analizi Erkan ve Özden'e (2008) göre yapılmıştır. 532 nm de spektrofotometrede okuma yapılmıştır ve spektrofotometrede okunan örnek sonuçları standartların regresyon eğrisi denklemi üzerinden hesaplanarak aşağıdaki formülde yerine konmuştur.

TBA değeri (mg MDA/kg balıketi): Standart eğriden okunan MDA değeri x dilüsyon faktörü/ örnek ağırlığı

3.1.4. Toplam uçucu bazik nitrojen (TVB-N)

Antonabopoulos ve Vyncke'nin (1989) geliştiridiği destilasyon metoduna göre yapılmıştır. Sonuçlar mg/100g olarak hesaplanmıştır.

3.1.5. Duyusal Analiz

Soğuk dumanlanmış somon için Amerina ve ark.'nın (1965) geliştirdiği skala kullanılmıştır. Bu skalaya göre 7-9 puan alan örnek "çok iyi", 6-6.9 puan alan örnek "iyi", 5-5.9 puan alan örnek kabul edilebilir kalite" ve 4.9-1.0 puan örnek "kabul edilemez" olarak değerlendirilmiştir.

Değerlendirmede su ürünlerinin kalite kontrolü konusunda deneyimi olan 5 panelist görev almıştır.

3.1.6. Mikrobiyolojik Analiz

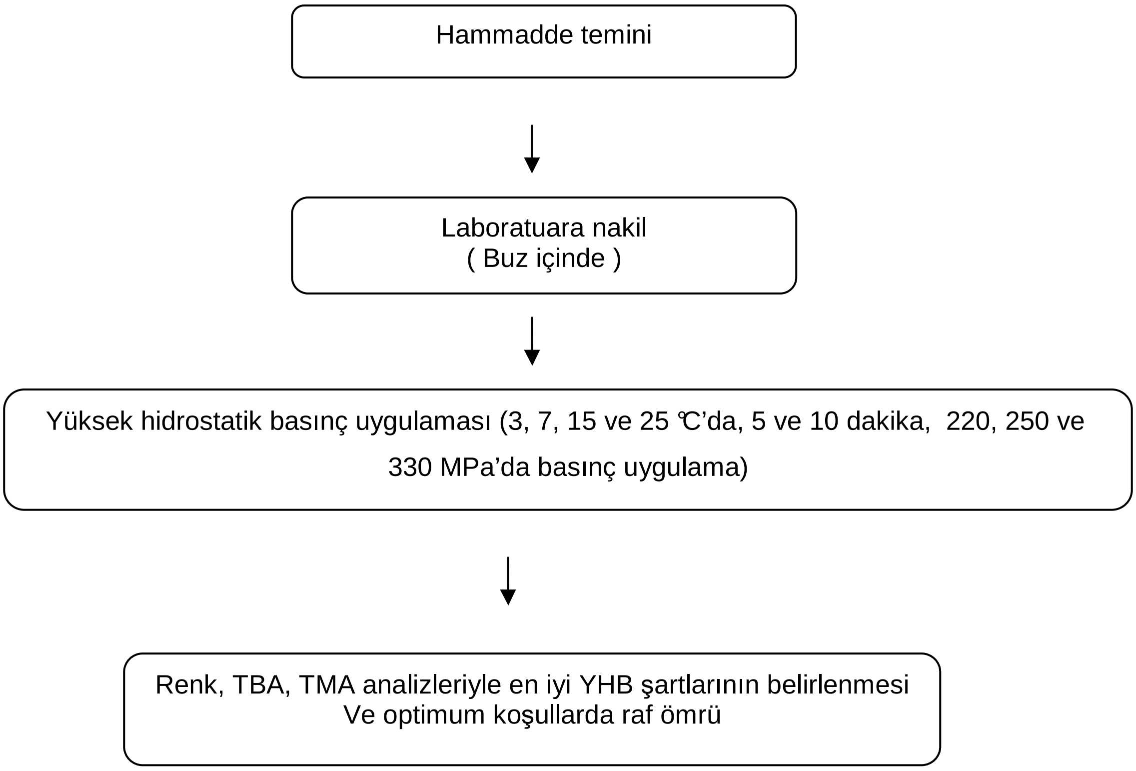
Mikrobiyolojik analizler Baumgart (1986) kaynak alınarak yapılmıştır. Besi yeri olarak PCA, Merck, Cat No: 105463 kullanılmış mezofilik aerobik bakteri yükü için 37ºC'de 24-48 saat, psikrotrofik bakteri yükü içinde 7ºC'de 10 gün inkübasyon yapılmıştır.

3.2. YSB uygulamasının tekirin *(Mullus surmutelus)* kalite parametreleri ve raf ömrü üzerine etkisi

Yağlı balık olarak tekir *(Mullus surmutelus)* kullanılarak 3, 7, 15 ve 25℃'de 5 ve 10 dakika süre 220, 250 ve 330 MPa kombinasyonlarında en iyi YHB şartlarını belirleyebilmek için renk, Trimetilamin azot (TMA-N) ve Tiyobarbitürik asit sayısı (TBA) analizleri yapılmıştır (Şekil 3.2.1).

Ayrıca tekir için belirlenen en iyi koşullarda 4ºC'de raf ömrü çalışması duyusal, kimyasal ve mikrobiyolojik analizler yapılarak takip edilmiş ve kontrol grubuyla karşılaştırılmıştır.

Balık örnekleri Ankara Büyükşehir Belediyesi Balık Pazarından sabahın erken saatlerinde temin edilmiştir, balıklar strafor kutular içerisinde buzlu olarak soğuk zincir şartlarına uygun olarak YSB laboratuvarına getirilmiştir. Balıklar, ayıklanıp temiz içme suyuyla yıkandıktan sonra suları süzdürülmüş ve porsiyonlar halinde streç filmle sarılarak, Yüksek Hidrostatik Basınç cihazının haznesine yerleştirilmiştir.



Şekil 3.2.1 Tekir (*Mullus surmutelus*) için uygulanan çalışmanın akış şeması

Sonuçlar, paralellerin ortalaması alınarak ± standart sapma (SD) olarak verilmiştir. Çoklu karşılaştırmalar için parametrik varsayımların gerçekleştiği verilerde tek yönlü varyans analizi (ANOVA) uygulanmıştır. Bu test ile fark bulunan gruplarda, farklılığın nereden kaynaklandığını bulmak için Tukey testi kullanılmıştır. Gruplar arası ve depolamaya bağlı parametrelerde değerlendirmeler ve parametreler arası ilişki $P<0,05$ olması anlamlı kabul edilmiştir. Bu analizler İstanbul Üniversitesi Su Ürünleri Fakültesi, İşleme Teknolojisi Laboratuarlarında gerçekleştirilmiştir.

3.2.1. Renk Analizi

Her grup örnekte et üzerinden 3 noktadan renk ölçümü yapılmıştır. Hunter Lab sisteminde L^*parlaklığı (0'dan 100'e kadar derecelendirme siyahtan beyaza renk dağılımını); a^* pozitif değerdeyken kırmızı negatif değerde yeşili ve b^* pozitif değerde sarıyı negatif değerdeyken mavi renk aralığını ifade etmektedir. ΔE (renk farkı)= $(\Delta L^2+\Delta a^2+\Delta b^2)$'nin karekökünün alınması ile hesaplanmıştır (Gerdes ve Santos Valdez, 1991).

3.2.2. Toplam uçucu bazik nitrojen (TVB-N)

Antonabopoulos ve Vyncke (1989) 'un geliştiridiği destilasyon metoduna göre yapılmıştır. Sonuçlar mg/100g olarak hesaplanmıştır.

3.2.3. Trimetilamin Azot (TMA-N)

Trimetilamin azot (TMA-N) analizi AOAC (1998)' e göre yapılmıştır. Spektrofotometre olarak UV/VIS double beam spectrophotometer T80 Series (PG Instruments Ltd., Wibtoft. Leics. İngiltere) kullanılmıştır.

TMA değeri (mg/100 g balık eti): Standart eğriden okunan TMA değeri x dilüsyon faktörü/ örnek ağırlığı

3.2.4.Tiyobarbitürik Asit Sayısı Tayini (TBA)

TBA analizi Erkan ve Özden (2008)'e göre yapılmıştır. 532 nm de spektrofotometrede okuma yapılmıştır ve spektrofotometrede okunan örnek sonuçları standartların regresyon eğrisi denklemi üzerinden hesaplanarak aşağıdaki formülde yerine konmuştur.

TBA değeri (mg MDA/kg balıketi): Standart eğriden okunan MDA değeri x dilüsyon faktörü/ örnek ağırlığı

3.2.5. Duyusal Analiz

Duyusal değerlendirmede tekir balığı için Huss'un (1988) geliştirdiği skala kullanılmıştır. Bu skalaya göre örneklerin genel görünüşü ve kokusunda meydana gelen değişimler panelistlerce 10 puan üzerinden değerlendirilmiştir. Duyusal değerlendirmede kullanılan form örneği Tablo 3.2.5'de verilmiştir.

Tablo 3.2.5. Duyusal değerlendirmede kullanılan skala

Tarih	**Panelistin Adı:**		
Skor	**Kalite Değerlendirmesi**	**Genel görünüş için verilen puan**	**Koku için verilen puan**
10-9	Çok iyi kalite		
8,9-8	Iyi kalite		
7,9-6	Orta kalite		
5,9-4	Tüketilebilir		
3,9-0	Tüketilemez		

Değerlendirmede su ürünlerinin kalite kontrolü konusunda deneyimi olan 5 panelist görev almıştır.

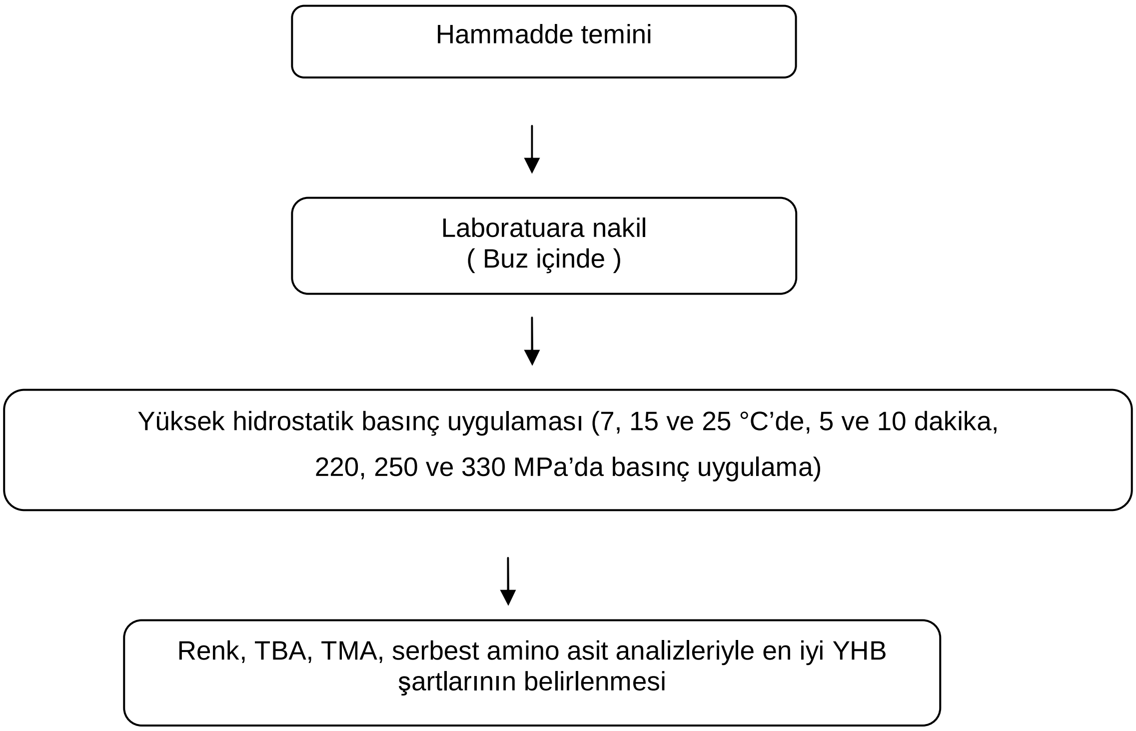
3.2.6. Mikrobiyolojik Analiz

Mikrobiyolojik analizler Baumgart (1986) kaynak alınarak yapılmıştır. Besi yeri olarak PCA, Merck, Cat No: 105463 kullanılmış mezofilik aerobik bakteri yükü için 37ºC’de 24-48 saat, psikrotrofik bakteri yükü içinde 7ºC’de 10 gün inkübasyon yapılmıştır.

3.3. YSB uygulamasının kültür alabalığı *(Onchorynchus mykiss)* ve istavrit *(Trachurus trachurus)* kalite parametreleri ve serbest aminoasit miktarı üzerine etkileri

Kültür alabalığı *(Onchorynchus mykiss)* ve istavrit *(Trachurus trachurus)* ullanılarak 7, 15 ve 25℃’de 5 ve 10 dakika süre ile 220, 250 ve 330 MPa kombinasyonlarında en iyi YHB şartlarını belirleyebilmek için renk, Trimetilamin azot (TMA-N), Tiyobarbitürik asit sayısı (TBA) ve serbest amino asit analizleri yapılmış ve kontrol grubuyla karşılaştırılmıştır (Şekil 3.3.1).

Kafeslerde yetiştirilen kültür alabalıkları projeyi destekleyen firmalardan temin edilmiş ve toplam 3 kg alabalık buzlu-soğuk suda öldürüldükten sonra (hipotermi) (Council Directive 86/609/EEC) buzlu strafor kutularda-drenaj delikleri açılarak- paketlenmiş (2:1, balık:buz) (Council Directive 91/493/EEC) ve soğuk zincir şartlarına uygun olarak YSB laboratuvarına getirilmiştir. İstavrit balıkları normal balıkçıdan temin edilmiştir. Balıklar, ayıklanıp temiz içme suyuyla yıkandıktan sonra suları süzdürülmüş ve porsiyonlar halinde streç filmle sarılarak, Yüksek Hidrostatik Basınç cihazının haznesine yerleştirilmiştir.



Şekil 3.3.1 Alabalık ve istavrit için uygulanan çalışmanın akış şeması

Sonuçlar, paralellerin ortalaması alınarak ± standart sapma (SD) olarak verilmiştir. Çoklu karşılaştırmalar için parametrik varsayımların gerçekleştiği verilerde tek yönlü varyans analizi (ANOVA) uygulanmıştır. Bu test ile fark bulunan gruplarda, farklılığın nereden kaynaklandığını bulmak için Tukey testi kullanılmıştır. Gruplar arası ve depolamaya bağlı parametrelerde değerlendirmeler ve parametreler arası ilişki $P<0,05$ olması anlamlı kabul edilmiştir. Bu analizler İstanbul Üniversitesi Su Ürünleri Fakültesi, İşleme Teknolojisi Laboratuarlarında gerçekleştirilmiştir.

3.3.1. Fiziksel analizler:

3.3.1.1.Renk Analizi

Her grup örnekte et üzerinden 10 noktadan renk ölçümü yapılmıştır. Hunter Lab sisteminde L^*parlaklığı (0'dan 100'e kadar derecelendirme siyahtan beyaza renk dağılımını); a^* pozitif değerdeyken kırmızı negatif değerde yeşili ve b^* pozitif değerde sarıyı negatif değerdeyken mavi renk aralığını ifade etmektedir. ΔE (renk farkı)= ($\Delta L^2+\Delta a^2+\Delta b^2$)'nin karekökünün alınması ile hesaplanmıştır (Gerdes ve Santos Valdez, 1991).

3.3.2. Kimyasal analizler:

3.3.2.1.Trimetilamin Azot (TMA-N)

Trimetilamin azot (TMA-N) analizi AOAC (1998)' e göre yapılmıştır. Spektrofotometre olarak UV/VIS double beam spectrophotometer T80 Series (PG Instruments Ltd., Wibtoft. Leics. İngiltere) kullanılmıştır.

TMA değeri (mg/100 g balık eti): Standart eğriden okunan TMA değeri x dilüsyon faktörü/ örnek ağırlığı

3.3.2.2. Tiyobarbitürik Asit Sayısı Tayini (TBA)

TBA analizi Erkan ve Özden (2008)'e göre yapılmıştır. 532 nm de spektrofotometrede okuma yapılmıştır ve spektrofotometrede okunan örnek sonuçları standartların regresyon eğrisi denklemi üzerinden hesaplanarak aşağıdaki formülde yerine konmuştur.

TBA değeri (mg MDA/kg balıketi): Standart eğriden okunan MDA değeri x dilüsyon faktörü/ örnek ağırlığı

3.3.2.3. Serbest aminoasit tayini

YHB uygulanmış ve uygulanmamış örneklerin serbest amino asit tayini Erkan ve ark. (2010)'a göre yapılmış ve sonuçlar ağırlık bazında verilmiştir.

4. Bulgular ve Tartışma

4.1. YSB uygulamasının somon örneklerindeki kalite parametreleri üzerine etkileri

220, 250 ve 330 MPa'da 3, 7, 15 ve 25°C'da 5 ve 10 dakika süre kombinasyonlar uygulanmış somon örneklerinde elde edilen Trimetilamin azot (TMA-N), Tiyobarbitürik asit sayısı (TBA) ve renk değişimleri aşağıda verilmiştir (Tablo 4.1.1 ve 4.1.2).

Tablo 4.1.1. Basınçlı dumanlanmış somon örneklerinin TMA-N ve TBA içeriğindeki değişimler
(Büyük harfler her kolondaki gruplar arası farkı, küçük harfler her satırdaki gruplar arası farkı ifade etmektedir.)

Sıcaklık/süre		3 °C/5 dk	3 °C/10 dk	7 °C/5 dk	7 °C/10 dk	15 °C/5 dk	15°C/ 10 dk	25°C/5 dk	25°C/ 10 dk
TMA-N	**Kont-rol**	0.69 ± 0.07 *ai*	0.69 ± 0.07 *ai*	0.69 ± 0.07 *ai*	0.69 ± 0.07 *ai*	0.69 ± 0.07 *ai*	0.69 ± 0.07 *ai*	0.69 ± 0.07 *ai*	0.69 ± 0.07 *ai*
	220 MPa	0.85 ± 0.08 *bi*	0.87 ± 0.08 *bi*	0.30 ± 0.06 *bj*	0.68 ± 0.31 ak	0.84 ± 0.11 *bi*	0.76 ± 0.05 *bl*	0.78 ± 0.20 *bl*	0.52 ± 0.25 *bm*
	250 MPa	0.93 ± 0.09 *ci*	0.58 ± 0.32 *cj*	0.57 ± 0.10 *cj*	0.89 ± 0.16 *bk*	0.92 ± 0.09 *ck*	0.76 ± 0.06 *bl*	0.48± 0.03 mc	0.55 ± 0.22 *bj*
	330 MPa	0.83 ± 0.05 *bi*	0.88 ± 0.09 *bi*	0.26 ± 0.12 *bj*	1.00 ± 0.09 *bk*	0.79 ± 0.07 *bl*	0.62 ± 0.08 *am*	0.25 ± 0.01 *dn*	0.43 ± 0.20 *co*
TBA	**Kont-rol**	3.68 ± 0.22 *ai*	3.68 ± 0.22 *ai*	3.68 ± 0.22 *a*	3.68 ± 0.22 *ai*	3.68 ± 0.22 *ai*	3.68 ± 0.22 *ai*	3.68 ± 0.22 *ai*	3.68 ± 0.22 *ai*
	220 MPa	3.70 ± 0.24 *ai*	4.43 ± 0.18 *bj*	4.43 ± 0.39 *bj*	4.79 ± 0.14 *bl*	3.87 ± 0.62 *bm*	3.56 ± 0.32 *bn*	3.98 ± 0.95 *o*	3.96 ± 0.96 *bo*
	250 MPa	3.47 ± 0.23 *bi*	4.76 ± 0.36 *cj*	4.36 ± 0.19 *bk*	4.82 ± 0.50 *bl*	3.71 ± 0.16 *am*	3.67 ± 0.18 *am*	4.19 ± 0.08 *cn*	3.92 ± 0.87 *bo*
	330 MPa	4.05 ± 0.33 *ci*	5.12 ± 0.32 *dj*	4.60 ± 0.29 *cki*	4.49 ± 0.44 *cl*	4.11 ± 0.55 *cm*	3.86 ± 0.16 *cn*	4.10 ± 0.09 *cm*	3.99 ± 0.90 *bm*

Tablo 4.1.2. Basınçlı dumanlanmış somon örneklerinin renk değerlerindeki değişimler
(Büyük harfler her kolondaki gruplar arası farkı, küçük harfler her satırdaki gruplar arası farkı ifade etmektedir.)

Sıcaklık/süre		3 °C/5 dk	3 °C/10 dk	7 °C/5 dk	7 °C/10 dk	15 °C/5 dk	15°C/ 10 dk	25 °C/ 5 dk	25°C/ 10 dk
L*	Kontrol	54.1 ± 2.1^{ai}	54.1 ± 2.1^{ai}	54.1 ± 2.1^{ai}	54.1 ± 2.1^{ai}	54.1 ± 2.1^{ai}	54.1 ± 2.1^{ai}	54.1 ± 2.1^{ai}	54.1 ± 2.1^{ai}
	220 MPa	53.5 ± 1.9^{ai}	56.3 ± 2.0^{bj}	52.6 ± 1.9^{ai}	53.1 ± 3.3^{ai}	49.7 ± 1.8^{bk}	48.8 ± 1.2^{bk}	47.8 ± 1.3^{bk}	50.2 ± 3.2^{bl}
	250 MPa	52.0 ± 1.7^{ai}	52.1 ± 1.4^{ai}	53.8 ± 2.1^{ai}	54.2 ± 0.5^{ai}	49.6 ± 4.2^{bj}	52.0 ± 3.9^{ai}	55.3 ± 1.9^{al}	54.6 ± 2.1^{al}
	330 MPa	58.4 ± 2.5^{bi}	55.8 ± 1.0^{bj}	55.5 ± 1.4^{bj}	56.7 ± 1.1^{bj}	55.6 ± 0.6^{aj}	54.2 ± 1.9^{aj}	56.2 ± 1.5^{bj}	55.7 ± 2.2^{aj}
a*	Kontrol	20.7 ± 1.9^{ai}	20.7 ± 1.9^{ai}	20.7 ± 1.9^{ai}	20.7 ± 1.9^{ai}	20.7 ± 1.9^{ai}	20.7 ± 1.9^{ai}	20.7 ± 1.9^{ai}	20.7 ± 1.9^{ai}
	220 MPa	21.1 ± 1.1^{ai}	20.2 ± 3.0^{ai}	22.5 ± 1.2^{ai}	22.3 ± 1.8^{bi}	18.9 ± 2.8^{bj}	19.9 ± 3.9^{aj}	20.7 ± 2.7^{ai}	23.1 ± 1.7^{bk}
	250 MPa	19.4 ± 2.5^{ai}	19.3 ± 0.9^{ai}	20.9 ± 2.6^{aj}	17.3 ± 2.7^{ck}	20.0 ± 1.4^{aj}	19.7 ± 3.1^{aj}	20.6 ± 2.7^{aj}	23.0 ± 1.6^{bk}
	330 MPa	22.4 ± 3.2^{ai}	19.6 ± 1.1^{aj}	21.3 ± 0.7^{ak}	21.2 ± 1.5^{bk}	21.0 ± 1.8^{ak}	18.8 ± 1.5^{bl}	18.8 ± 1.0^{bl}	19.8 ± 0.4^{aj}
b*	Kontrol	28.5 ± 1.5^{ai}	28.5 ± 1.5^{ai}	28.5 ± 1.5^{ai}	28.5 ± 1.5^{ai}	28.5 ± 1.5^{ai}	28.5 ± 1.5^{ai}	28.5 ± 1.5^{ai}	28.5 ± 1.5^{ai}
	220 MPa	27.7 ± 0.9^{ai}	31.6 ± 6.6^{bj}	29.6 ± 2.2^{ak}	28.8 ± 3.7^{ak}	26.8 ± 3.0^{bl}	27.3 ± 2.3^{al}	27.5 ± 3.8^{al}	28.7 ± 2.3^{ak}
	250 MPa	27.8 ± 2.1^{ai}	27.1 ± 1.7^{ai}	29.4 ±4.6^{aj}	25.0 ± 3.8^{bk}	25.0 ± 2.7^{ck}	27.1 ± 3.8^{ai}	27.2 ±3.4^{ai}	28.2 ± 2.1^{ai}
	330 MPa	29.2 ± 3.0^{ai}	25.7 ± 2.0^{cj}	28.1 ± 1.1^{ai}	27.6 ± 2.2^{ai}	28.9 ± 1.8^{ai}	23.3 ± 2.3^{bk}	25.8 ± 1.9^{bl}	24.9 ± 1.1^{bl}
ΔE	Kontrol	5.5 ± 0.9^{ai}	5.5 ± 0.9^{ai}	5.5 ± 0.9^{ai}	5.5 ± 0.9^{ai}	5.5 ± 0.9^{ai}	5.5 ± 0.9^{ai}	5.5 ± 0.9^{ai}	5.5 ± 0.9^{ai}
	220 MPa	2.5 ± 1.1^{bi}	7.2 ± 4.5^{bj}	3.9 ± 1.0^{bk}	5.3 ± 1.6^{al}	6.8 ± 0.9^{bm}	6.9 ± 2.0^{bm}	7.8 ± 1.8^{bn}	6.0 ± 1.5^{ao}
	250 MPa	4.4 ± 0.8^{ci}	3.5 ± 1.2^{cj}	5.3 ± 2.0^{ak}	5.9 ± 3.0^{al}	6.4 ± 4.2^{bm}	6.2 ± 2.0^{cm}	4.7 ± 1.8^{ci}	3.9 ± 1.0^{bj}
	330 MPa	6.5 ± 2.4^{di}	4.1 ± 1.1^{dj}	2.3 ± 0.9^{ck}	3.8 ± 1.3^{bl}	3.0 ± 0.4^{cm}	6.0 ± 2.2^{cn}	4.6 ± 1.3^{c}	4.6 ± 0.7^{an}

Renk, TMA-N ve TBA analiz sonuçları toplu olarak değerlendirildiğinde (kontrol örneğinin değerlerine yakın veya daha düşük L*, a*, b*, TMA-N ve TBA değerleri baz alınarak) soğuk dumanlanmış somon için 3ºC/5dk/250 MPa ve 25ºC/10dk/250MPa YHB uygulamasının en iyi kombinasyonlar olduğu tespit edilmiştir ve raf ömrü çalışmaları bu iki YSB kombinasyonunda gerçekleştirilmiştir.

4.2. YSB uygulamasının dumanlanmış somonun raf ömrü üzerine etkileri

Dumanlanmış somon balığının 2ºC'deki raf ömrü (duyusal, kimyasal ve mikrobiyolojik analizler) yapılarak incelenmiştir (Tablo 4.2.1-4.2.4).

Tablo 4.2.1. Soğukta (2ºC) depolama sırasında soğuk dumanlanmış somonun duyusal parametrelerinde meydana gelen değişimler

(Büyük harfler her kolondaki gruplar arası farkı, küçük harfler her satırdaki gruplar arası farkı ifade etmektedir.)

Depolama Süresi (hafta)		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Genel Görü-nüş	**Kontrol**	8.67 ±0.47 ^{Aa}	7.67 ± 0.47 ^{Ab}	7.50 ± 0.41 ^{Ab}	7.33 ± 0.47 ^{Ab}	6.00 ± 0.41 ^{Ac}	5.67 ± 0.48 ^{Ac}	4.50 ± 0.41 ^{Ad}	4.00 ± 0.82 ^{Ad}
	250 MPa, 3 ºC, 5 dk	8.40 ± 0.65 ^{Ab}	8.40 ± 0.29 ^{Bb}	8.00 ± 0.41 ^{Bb}	7.50 ± 1.08 ^{Bc}	6.83 ± 0.62 ^{Bd}	6.27 ± 0.21 ^{Bd}	5.67 ± 0.24 ^{Be}	4.83 ± 0.47 ^{Bf}
	250 MPa, 25 ºC, 10 dk	8.73 ± 0.21 ^{Aa}	7.63 ± 1.16 ^{Aa}	7.50 ± 0.41 ^{Aa}	7.27 ± 0.95 ^{Ab}	6.93 ± 0.33 ^{Bb}	6.17 ± 0.47 ^{Bc}	6.00 ± 0.71 ^{Bd}	5.17 ± 0.24 ^{Be}
Koku	**Kontrol**	8.67 ± 0.24 ^{Aa}	7.73 ± 0.52 ^{Ab}	7.50 ± 0.41 ^{Ab}	7.57 ± 0.84 ^{Ab}	6.00 ± 0.41 ^{Ac}	5.83 ± 0.62 ^{Ac}	4.70 ± 0.22 ^{Ad}	4.33 ± 0.94 ^{Ae}
	250 MPa, 3 ºC, 5 min	7.80 ± 1.30 ^{Ba}	7.71 ± 0.85 ^{Aa}	7.53 ± 0.41 ^{Aa}	7.83 ± 0.53 ^{Ba}	6.20 ± 0.51 ^{Bb}	6.13 ± 0.19 ^{Bb}	5.40 ± 0.43 ^{Bc}	5.33 ± 0.47 ^{Bc}
	250 MPa, 25 ºC, 10 min	8.67 ± 0.47 ^{Aa}	7.93 ± 0.66 ^{Ab}	7.50 ± 0.61 ^{Bb}	7.27 ± 0.41 ^{Ab}	6.70 ± 0.47 ^{Bc}	6.43 ± 0.33 ^{Bc}	5.67 ± 0.24 ^{Bd}	5.50 ± 0.41 ^{Bd}
Tat	**Kontrol**	8.63 ± 0.26 ^{Aa}	8.13 ± 0.19 ^{Aa}	7.17 ± 0.62 ^{Aa}	7.50 ± 0.81 ^{Aa}	6.10 ± 0.37 ^{Ab}	5.83 ± 0.62 ^{Ab}	4.33 ± 0.47 ^{Ac}	4.00 ± 0.81 ^{Ac}
	250 MPa, 3 ºC, 5 dk	8.53 ± 1.23 ^{Aa}	8.03 ± 0.44 ^{Aa}	7.37 ± 0.58 ^{Aa}	7.43 ± 0.66 ^{Aa}	6.40 ± 0.43 ^{Bb}	6.13 ± 0.18 ^{Bb}	5.53 ± 0.47 ^{Bb}	5.33 ± 0.45 ^{Bc}
	250 MPa, 25 ºC, 10 dk	9.17 ± 0.62 ^{Ab}	8.00 ± 0.40 ^{Aa}	7.27 ± 0.21 ^{Ab}	7.46 ± 1.05 ^{Aa}	6.83 ± 0.46 ^{Bb}	6.10 ± 0.50 ^{Bb}	5.67 ± 0.24 ^{Bc}	5.33 ± 0.24 ^{Bc}
Doku	**Control**	8.93 ± 0.49 ^{Aa}	7.60 ± 0.78 ^{Aa}	7.60 ± 0.24 $^{A a}$	6.93 ± 0.82 ^{Aa}	6.33 ± 0.62 ^{Aa}	6.00 ± 0.41 ^{Ab}	5.00 ± 0.10 ^{Ac}	4.33 ± 0.62 ^{Ad}
	250 MPa, 3 ºC, 5 dk	8.17 ± 0.62 ^{Ba}	7.60 ± 1.13 ^{Aa}	7.50 ± 0.41 ^{Aa}	7.30 ± 0.47 ^{Ba}	6.40 ± 0.20 ^{Bb}	6.00 ± 0.41 ^{Ab}	5.23 ± 0.21 ^{Bc}	4.83 ± 0.24 ^{Bc}
	250 MPa, 25 ºC, 10 dk	8.83 ± 0.24 ^{Aa}	7.83 ± 0.94 ^{Aa}	7.60 ± 0.65 ^{Aa}	6.90 ± 0.64 ^{Aa}	6.43 ± 0.42 ^{Bb}	6.23 ± 0.52 ^{Bb}	5.43 ± 0.09 ^{Bc}	5.33 ± 0.24 ^{Cc}

Genel görünüş, koku, tat, ve doku parametrelerinin ortalaması alındığında depolamanın 6. haftasından sonra tüketilebilirlik limitinin aşıldığı göstermektedir. Basınçlanmış somon örneklerinde bu limit 8 hafta boyunca aşılmamıştır.

Tablo 4.2.2. Soğukta (2ºC) depolama sırasında soğuk dumanlanmış somonun renk değerlerinde meydana gelen değişimler

(Büyük harfler her kolondaki gruplar arası farkı, küçük harfler her satırdaki gruplar arası farkı ifade etmektedir.

Depolama Süresi (hafta)		1	2	3	4	5	6	7	8
L*	**Kontrol**	39.9 ± 3.9 ^{Aa}	40.7 ± 2.9 ^{Aa}	42.6 ± 2.7 ^{Aa}	40.9 ± 2.0 ^{Aa}	42.8 ± 2.3 ^{Aa}	47.0 ± 3.5 ^{Aa}	44.3 ± 3.2 ^{Aa}	44.8 ± 3.1 ^{Aa}
	250 MPa, 3 ºC, 5 dk	44.0 ± 2.1 ^{Ba}	47.4 ± 2.4 ^{Bb}	42.1 ± 2.0 ^{Aa}	43.4 ± 1.9 ^{Ba}	45.3 ± 1.7 ^{Ba}	49.5 ± 3.6 ^{Ab}	46.8 ± 2.3 ^{Bb}	46.7 ± 3.2 ^{Bb}
	250 MPa, 25 ºC, 10 dk	46.8 ± 2.2 ^{Ba}	43.5 ± 3.4 ^{Aa}	42.0 ± 3.2 ^{Aa}	43.4 ± 4.5 ^{Ba}	46.9 ± 5.5 ^{Ba}	53.4 ± 0.8 ^{Bb}	47.5 ± 1.9 ^{Ba}	47.5 ± 3.9 ^{Ba}
a*	**Kontrol**	18.9 ± 3.3 ^{Aa}	17.8 ± 1.5 ^{Aa}	20.7 ± 2.8 ^{Aa}	17.7 ± 0.6 ^{Aa}	19.0 ± 2.2 ^{Aa}	23.2 ± 3.4 ^{Aa}	17.5 ± 2.7 ^{Aa}	18.6 ± 1.7 ^{Aa}
	250 MPa, 3 ºC, 5 dk	20.3 ± 3.4 ^{Aa}	22.5 ± 3.4 ^{Ba}	22.4 ± 0.8 ^{Ba}	20.9 ± 1.3 ^{Ba}	21.4 ± 1.2 ^{Ba}	23.2 ± 5.6 ^{Aa}	20.1 ± 1.3 ^{Ba}	18.2 ± 1.2 ^{Aa}
	250 MPa, 25 ºC, 10 dk	24.5 ± 1.6 ^{Ba}	20.9 ± 2.8 ^{Ba}	19.9 ± 3.1 ^{Aa}	22.2 ± 2.3 ^{Ba}	22.0 ± 2.2 ^{Ba}	29.7 ± 1.5 ^{Bb}	20.8 ± 3.3 ^{Bc}	17.8 ± 3.2 ^{Ac}
b*	**Kontrol**	22.5 ± 5.0 ^{Aa}	22.3 ± 3.9 ^{Aa}	24.8 ± 4.0 ^{Aa}	21.9 ± 2.9 ^{Aa}	23.2 ± 4.3 ^{Aa}	33.3 ± 8.1 ^{Aa}	25.8 ± 4.9 ^{Aa}	27.1 ± 3.3 ^{Aa}
	250 MPa, 3 ºC, 5 dk	25.6 ± 5.3 ^{Ba}	30.1 ± 4.8 ^{Ba}	24.8 ± 2.3 ^{Aa}	24.8 ± 0.5 ^{Ba}	27.4 ± 3.6 ^{Ba}	33.7 ± 7.5 ^{Aa}	27.6 ± 3.6 ^{Ba}	26.6 ± 3.4 ^{Aa}
	250 MPa, 25 ºC, 10 dk	27.4 ± 3.0 ^{Ba}	25.3 ± 5.2 ^{Ca}	22.6 ± 3.4 ^{Aa}	27.8 ± 2.1 ^{Ca}	29.2 ± 3.2 ^{Ba}	43.8 ± 1.6 ^{Bb}	28.2 ± 3.7 ^{Ba}	28.7 ± 5.1 ^{Aa}
ΔE	**Kontrol**	5.7 ± 3.7 ^{Aa}	4.3 ± 2.3 ^{Aa}	3.0 ± 1.1 ^{Aa}	3.2 ± 1.1 ^{Aa}	5.2 ± 1.3 ^{Aa}	7.8 ± 4.7 ^{Aa}	5.6 ± 2.5 ^{Aa}	4.3 ± 1.6 ^{Aa}
	250 MPa, 3 ºC, 5 dk	8.3 ± 3.3 ^{Ba}	12.2 ± 4.2 ^{Bb}	3.3 ± 4.2 ^{Aa}	5.4 ± 1.0 ^{Ba}	5.4 ± 2.2 ^{Aa}	8.5 ± 4.1 ^{Aa}	5.4 ± 2.0 ^{Aa}	4.6 ± 1.9 ^{Aa}
	250 MPa, 25 ºC, 10 dk	10.8 ± 3.4 ^{Ba}	7.3 ± 4.2 ^{Ca}	5.4 ± 4.2 ^{Ba}	9.2 ± 2.1 ^{Ca}	8.3 ± 4.0 ^{Ba}	14.0 ± 1.8 ^{Ba}	6.6 ± 3.0 ^{Ba}	6.4 ± 4.1 ^{Ba}

Tablo 4.2.3. Soğukta (2ºC) depolama sırasında soğuk dumanlanmış somonun pH, TVB-N, TMA-N ve TBA değerlerinde meydana gelen değişimler

(Büyük harfler her kolondaki gruplar arası farkı, küçük harfler her satırdaki gruplar arası farkı ifade etmektedir

Depolama Süresi (hafta)		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
pH	**kontrol**	6.19 ± 0.3 ^{Aa}	6.16 ± 0.3 ^{Aa}	5.96 ± 0.1 ^{Aa}	5.69 ± 0.5 ^{Ab}	5.85 ± 0.2 ^{Ab}	6.11 ± 0.1 ^{Aa}	6.0 ± 0.2 ^{Aa}	6.73 ± 0.1 ^{Ac}
	250 MPa, 3 ºC, 5 dk	6.18 ± 0.2 ^{Aa}	6.07 ± 0.4 ^{Bb}	5.93 ± 0.2 ^{Ab}	5.93 ± 0.5 ^{Bb}	5.95 ± 0.1 ^{Ab}	5.7 ± 0.1 ^{Bb}	6.07 ± 0.0 ^{Ab}	6.15 ± 0.4 ^{Bb}
	250 MPa, 25 ºC, 10 dk	6.14 ± 0.1 ^{Ba}	6.08 ± 0.0 ^{Ba}	5.95 ± 0.1 ^{Ab}	5.79 ± 0.3 ^{Cb}	5.9 ± 0.1 ^{Ab}	5.86 ± 0.1 ^{Bb}	6.17 ± 0.1 ^{Ba}	6.17 ± 0.4 ^{Ba}
TVB-N mg/100g	**kontrol**	17.5 ± 0.2 ^{Aa}	16.3 ± 0.0 ^{Ab}	19.9 ± 1.2 ^{Ac}	15.6 ± 0.1 ^{Ad}	19.9 ± 2.0 ^{Ac}	18.7 ± 0.9 ^{Ac}	19.2 ± 1.6 ^{Ac}	31.7 ± 1.3 ^{Ae}
	250 MPa, 3 ºC, 5 dk	17.5 ± 0.2 ^{Aa}	14.7 ± 1.1 ^{Bb}	17.6 ± 0.7 ^{Ba}	14.7 ± 0.4 ^{Bb}	20.4 ± 0.6 ^{Ac}	20.0 ± 0.3 ^{Bc}	20.6 ± 0.1 ^{Bc}	20.0 ± 0.6 ^{Bc}
	250 MPa, 25 ºC, 10 dk	18.2 ± 1.0 ^{Ba}	20.1 ± 0.9 ^{Ca}	18.9 ± 1.6 ^{Ca}	15.5 ± 0.2 ^{Ab}	20.1 ± 0.3 ^{Aa}	21.6 ± 0.0 ^{Bc}	22.2 ± 1.1 ^{Cc}	20.6 ± 1.0 ^{Ba}
TMA-N mg/100g	**kontrol**	0.8 ± 0.0 ^{Aa}	0.9 ± 0.0 ^{Aa}	0.8 ± 0.0 ^{Aa}	0.9 ± 0.0 ^{Aa}	0.9 ± 0.0 ^{Aa}	0.9 ± 0.0 ^{Aa}	1.0 ± 0.0 ^{Aa}	1.0 ± 0.1 ^{Aa}
	250 MPa, 3 ºC, 5 dk	0.8 ± 0.0 ^{Aa}	0.8 ± 0.0 ^{Aa}	0.8 ± 0.0 ^{Aa}	0.9 ± 0.0 ^{Aa}	0.9 ± 0.0 ^{Aa}	0.9 ± 0.0 ^{Aa}	1.0 ± 0.0 ^{Aa}	0.9 ± 0.0 ^{Aa}
	250 MPa, 25 ºC, 10 dk	0.8 ± 0.0 ^{Aa}	0.9 ± 0.0 ^{Aa}	0.9 ± 0.0 ^{Aa}	0.9 ± 0.0 ^{Aa}	0.9 ± 0.0 ^{Aa}	0.9 ± 0.0 ^{Aa}	1.0 ± 0.0 ^{Aa}	0.9 ± 0.0 ^{Aa}
TBA mg MDA/kg	**kontrol**	1.5 ± 0.2 ^{Aa}	0.7 ± 0.0 ^{Ab}	0.8 ± 0.0 ^{Ab}	1.0 ± 0.1 ^{Ac}	0.8 ± 0.0 ^{Ac}	0.1 ± 0.0 ^{Ad}	0.1 ± 0.0 ^{Ad}	0.2 ± 0.1 ^{Ad}
	250 MPa, 3 ºC, 5 dk	1.3 ± 0.1 ^{Ba}	0.6 ± 0.0 ^{Ab}	0.7 ± 0.0 ^{Ab}	0.8 ± 0.1 ^{Ac}	0.8 ± 0.0 ^{Ac}	0.1 ± 0.0 ^{Ad}	0.1 ± 0.0 ^{Ad}	0.1 ± 0.0 ^{Ad}
	250 MPa, 25 ºC, 10 dk	1.6 ± 0.0 ^{Aa}	0.7 ± 0.0 ^{Ab}	0.7 ± 0.1 ^{Ab}	0.9 ± 0.0 ^{Ac}	0.7 ± 0.0 ^{Ab}	0.1 ± 0.0 ^{Ad}	0.1 ± 0.0 ^{Ad}	0.2 ± 0.0 ^{Ad}

Tablo 4.2.4 Soğukta (2ºC) depolama sırasında soğuk dumanlanmış somonun toplam mikrobiyolojik değerlerinde meydana gelen değişimler

(Büyük harfler her kolondaki gruplar arası farkı, küçük harfler her satırdaki gruplar arası farkı ifade etmektedir.

Depolama Süresi (hafta)		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Psikrotrofik	**Kontrol**	$< 3^{Aa}$	$< 3^{Aa}$	3^{Aa}	4.20^{Ab}	6.29^{Ac}	6.65^{Ad}	6.00^{Ae}	5.89^{Ae}
bakteri yükü	**250 MPa, 3 ºC, 5 dk**	$< 3^{Aa}$	$< 3^{Aa}$	$< 3^{Aa}$	$< 3^{Ba}$	$< 3^{Ba}$	$< 3^{Ba}$	$< 3^{Ba}$	$< 3^{Ba}$
(log kob/g)	**250 MPa, 25 ºC, 10 dk**	$< 3^{Aa}$	$< 3^{Aa}$	$< 3^{Aa}$	$< 3^{B}$	$< 3^{Ba}$	$< 3^{Ba}$	$< 3^{Ba}$	$< 3^{Ba}$
Mezofilik aerobik	**Kontrol**	$< 3^{Aa}$	$< 3^{Aa}$	$< 3^{Aa}$	3.80^{Ab}	4.63^{Ac}	4.84^{Ad}	5.50^{Ae}	5.90^{Af}
Bakteri yükü	**250 MPa, 3 ºC, 5 dk**	$< 3^{Aa}$	$< 3^{Aa}$	$< 3^{Aa}$	$< 3^{Ba}$	$< 3^{Ba}$	$< 3^{Ba}$	3^{Bb}	3.95^{Bc}
(log kob/g)	**250 MPa, 25 ºC, 10 dk**	$< 3^{Aa}$	$< 3^{Aa}$	$< 3^{Aa}$	$< 3^{Ba}$	$< 3^{Ba}$	$< 3^{Ba}$	3.17^{Bb}	4.11^{Bc}

Yukarıda detaylandırılan duyusal, kimyasal ve mikrobiyolojik analizler ışığında 2ºC'de 8 hafta süreyle saklanan basınçlanmamış dumanlanmış somon balıkları 6 haftalık raf ömrüne sahipken; YSB uygulamasının ilave olarak 2 haftalık raf ömrü artışı sağladığı gözlenmiştir.

4.3. YSB uygulamasının tekir *(Mullus surmutelus)* örneklerindeki kalite parametreleri üzerine etkileri

Yağlı balık türü olan tekir (Mullus surmutelus) kullanılarak 3, 7, 15 ve 25°C'de 5 ve 10 dakika süre 220, 250 ve 330 MPa kombinasyonlarında en iyi YHB şartlarını belirleyebilmek için renk, Trimetilamin azot (TMA-N) ve Tiyobarbitürik asit sayısı (TBA) analiz sonuçları aşağıda verilmiştir (Tablo 4.3.1 ve 4.3.2).

Tablo 4.3.1. Basınçlı tekir örneklerinin renk değerlerindeki değişimler

(Büyük harfler her kolondaki gruplar arası farkı, küçük harfler her satırdaki gruplar arası farkı ifade etmektedir.)

Sıcaklık/ Zaman		3 °C/ 5 dk	3 °C/ 10 dk	7 °C/ 5 dk	7 °C/ 10 dk	15 °C/ 5 dk	15 °C/ 10 dk	25 °C/ 5 dk	25 °C/ 10 dk
L*	Kontrol	50,87^{Aa}±2,67	50,87^{Aa} ±2,67	50,87^{Aa} ±2,67	50,87^{Aa} ±2,67	50,87^{Aa} ±2,67	50,87 ^{Aa}±2,67	50,87^{Aa} ±2,67	50,87 ^{Aa} ±2,67
	220 MPa	56,11^{Aa} ±1,04	66,20^{Bb} ±2,57	56,93^{Aa} ±2,58	63,74^{B} ±0,97	52,89 ^{Ba} ±3,54	52,34^{Ba} ±0,59	55,04^{Ba} ±1,81	56,87 ^{Ba} ±4,18
	250 MPa	65,71 ^{Ba}±3,30	63,9 ^{Ca} ±43,22	65,80^{Ba} ±2,64	64,50^{Ca}± 1,39	57,63 ^{Cb}±2,86	54,44 ^{Cb}±1,74	57,89 ^{Bb}±2,18	64,63 ^{Ca} ±1,64
	330 MPa	63,41^{Ba} ±1,10	59,70^{Da} ±2,65	68,64^{Cb} ±1,52	64,53^{Ca}± 1,39	61,34^{Da}± 2,22	66,90 ^{Da}±2,32	65,19 ^{Ca}±4,91	66,27 ^{Da} ±2,29
a*	Kontrol	4,36 ^{Aa} ±1,44	4,36 ^{Aa} ±1,44	4,36 ^{Aa} ±1,44	4,36 ^{Aa} ±1,44	4,36 ^{Aa} ±1,44	4,36 ^{Aa} ±1,44	4,36 ^{Aa} ±1,44	4,36 ^{Aa} ±1,44
	220 MPa	5,92 ^{Aa} ±1,74	2,46 ^{Bb} ±0,27	1,66 ^{Bc} ±0,90	3,47 ^{Ad} ±0,79	6,33 ^{Ba} ±1,48	4,80 ^{Aa} ±0,45	2,91 ^{Bb} ±0,26	2,89 ^{Bb} ±0,82
	250 MPa	4,24 ^{Aa} ±1,78	3,45 ^{Aa} ±1,26	3,38 ^{Aa} ±1,51	4,10 ^{Aa} ±0,20	3,10 Ca±0,3	6,17 ^{Bb} ±2,39	3,76 ^{Aa} ±0,94	2,55 ^{Bc} ±0,14
	330 MPa	3,83 ^{Aa} ±1,17	2,09 ^{Ba} ±1,54	2,28 ^{Ca} ±0,12	1,02 ^{Bb} ±0,44	3,21 ^{Ca} ±0,57	2,84 ^{Ca} ±0,89	3,80 ^{Aa} ±0,85	2,56 ^{Ba} ±0,13
b*	Kontrol	10,34^{Aa} ±1,17	10,34 ^{Aa}±1,17	10,34 ^{Aa}±1,17	10,34 ^{Aa}±1,17	10,34 ^{Aa}±1,17	10,34^{Aa} ±1,17	10,34^{Aa}± 1,17	10,34^{Aa} ±1,17
	220 MPa	12,03^{Ba} ±2,00	10,41^{Ab} ±0,40	8,90 ^{Bb} ±1,32	9,00 ^{Bb} ±1,19	13,89 ^{Aa} ±1,03	10,66^{Ab} ±0,74	9,21 ^{Bb} ±0,39	8,66 ^{Bb} ±1,15
	250 MPa	13,79^{Ca} ±0,51	8,38 ^{Bb} ±1,31	9,66 ^{Cb} ±1,08	10,16 ^{Ac} ±1,04	10,93 ^{Ac} ±2,12	12,65^{Ba} ±3,29	10,26 ^{Ac} ±0,86	9,26 ^{Cb} ±0,65
	330 MPa	8,99 ^{Da} ±1,84	7,73 ^{Ca} ±2,16	8,19 ^{Ba} ±0,54	6,94 ^{Cb} ±2,92	8,95 ^{Ba} ±0,38	7,09 ^{Ca} ±0,75	10,72 ^{Ac}±0,86	9,11 ^{Ca} ±1,25
ΔE	Kontrol	3,07 ^{Aa} ±1,10	3,07 ^{Aa} ±1,10	3,07 ^{Aa} ±1,10	3,07 ^{Aa} ±1,10	3,07 ^{Aa} ±1,10	3,07 ^{Aa} ±1,10	3,07 ^{Aa} ±1,10	3,07 ^{Aa} ±1,10
	220 MPa	6,94 ^{Ba} ±1,15	15,61^{Bb} ±1,10	6,94 ^{Ba} ±2,82	13,19^{Bc}± 1,10	6,08 ^{Ba} ±1,10	2,07 ^{Ad} ±0,33	3,91 ^{Ae} ±1,10	6,58 ^{Ba} ±4,26
	250 MPa	15,61^{Ca} ±3,01	13,50^{Ca} ±1,1	15,22^{Ca} ±2,76	13,84^{Ba}± 1,10	7,36 ^{Bb} ±2,93	5,84 ^{Bc} ±1,10	7,31 ^{Bb} ±1,10	14,08 ^{Ca} ±1,60
	330 MPa	12,45^{Da} ±1,86	9,74 ^{Db} ±1,10	18,17^{Dc} ±1,50	14,86^{Bd}± 1,10	10,78^{Ca}± 1,10	16,44^{Ce} ±1,10	14,57^{Cd}± 1,10	15,72 ^{Ce} ±2,31

Tablo 4.3.2. Basınçlı tekir örneklerinin TMA-N ve TBA içeriğindeki değişimler

(Büyük harfler her kolondaki gruplar arası farkı, küçük harfler her satırdaki gruplar arası farkı ifade etmektedir.)

	Sıcaklık/ Zaman	3 °C/ 5 dk	3 °C/ 10 dk	7 °C/ 5 dk	7 °C/ 10 dk	15 °C/ 5 dk	15 °C/ 10 dk	25 °C/ 5 dk	25°C/ 10 dk
TMA-N (mg/100g)	Kontrol	2,81^{Aa} ±0,19	2,81^{Aa} ±0,19	2,81^{Aa} ±0,19	2,81^{Aa} ±0,19	2,81^{Aa} ±0,19	2,81^{Aa} ±0,19	2,81^{Aa} ±0,19	2,81^{Aa} ±0,19
	220 MPa	3,92^{Ba} ±0,08	3,64^{Ba} ±0,15	3,84^{Ba} ±0,08	3,76^{Ba} ±0,04	5,66^{Bb} ±0,23	3,11^{Ac} ±0,21	2,92^{Ad} ±0,13	3,88^{Ba} ±0,23
	250 MPa	4,00^{Ba} ±0,07	3,80^{Ca} ±0,06	3,73^{Bb} ±0,04	3,09^{Ac} ±0,07	3,76^{Cb} ±0,24	3,85^{Ba} ±0,27	3,55^{Bb} ±0,14	2,83^{Ad} ±0,07
	330 MPa	2,91^{Aa} ±0,06	3,66^{Bb} ±0,06	3,51^{Bb} ±0,05	3,79^{Bb} ±0,16	4,45^{Dc} ±0,05	3,70^{Bb} ±0,09	3,97^{Cd} ±0,10	3,55^{Cb} ±0,10

	Sıcaklık/ Zaman	3 °C/ 5 dk	3 °C/ 10 dk	7 °C/ 5 dk	7 °C/ 10 dk	15 °C/ 5dk	15 °C/ 10 dk	25 °C/ 5 dk	25 °C/ 10 dk
TBA (mg MDA/kg)	Kontrol	1,53^{Aa} ±0,04	1,53^{Aa} ±0,04	1,53^{Aa} ±0,04	1,53^{Aa} ±0,04	1,53^{Aa} ±0,04	1,53^{Aa} ±0,04	1,53^{Aa} ±0,04	1,53^{Aa} ±0,04
	220 MPa	1,54^{Aa} ±0,02	1,61^{Aa} ±0,03	1,93^{Bb} ±0,13	1,83^{Bc} ±0,05	1,78^{Bc} ±0,06	1,82^{Bc} ±0,10	1,42^{Ba} ±0,07	1,38^{Bd} ±0,05
	250 MPa	1,71^{Ba} ±0,01	1,78^{Ba} ±0,03	1,64^{Ab} ±0,06	1,53^{Ab} ±0,03	1,55^{Ab} ±0,03	1,79^{Ca} ±0,05	1,58^{Ab} ±0,05	1,43^{Cc} ±0,05
	330 MPa	1,66^{Aa} ±0,05	1,73^{Bb} ±0,07	1,53^{Ac} ±0,09	1,68^{Aa} ±0,06	1,55^{Ac} ±0,06	1,66^{Aa} ±0,09	3,01^{Cd} ±0,09	1,45^{Ce} ±0,04

Renk, TMA-N ve TBA analiz sonuçları toplu olarak değerlendirildiğinde (kontrol örneğinin değerlerine yakın veya daha düşük L*, a*, b*, TMA-N ve TBA değerleri baz alınarak) tekir için 330 MPa/ 3ºC / 5dk ve 250MPa/ 25ºC /5 dk YHB uygulamasının en iyi kombinasyonlar olduğu tespit edilmiştir.

4.4. YSB uygulamasının tekir *(Mullus surmutelus)* örneklerindeki raf ömrü üzerine etkileri

Tekir için belirlenen en iyi koşullarda 4ºC'de raf ömrü (duyusal, kimyasal ve mikrobiyolojik analizler). çalışmasıyla ilgili duyusal, kimyasal ve mikrobiyolojik analiz sonuçları Tablo 4.4.1 – 4.4.9'da sırasıyla verilmiştir.

Tablo 4.4.1. Soğukta (4ºC) depolama sırasında tekirin duyusal parametrelerinde (genel görünüş) meydana gelen değişimler

(Büyük harfler her kolondaki gruplar arası farkı, küçük harfler her satırdaki gruplar arası farkı ifade etmektedir.)

Depolama günleri	1	3	5	7	9	11	13	15	17
Kontrol	9,00 ^{Aa} ±0,00	8,00 ^{Ab} ±0,00	7,20^{Ac} ±0,14	6,00 ^{Ac} ±1,41	4,00^{Ad} ±0,00	3,50 ^{Ad} ±0,71	2,50 ^{Ae} ±0,71	1,50^{Ae} ±0,71	0,85 ^{Af} ±0,21
330 MPa 3ºC 5 dk	9,00 ^{Aa} ±0,00	9,00 ^{Aa} ±0,00	8,35^{Bb} ±0,49	6,00 ^{Ac} ±0,00	5,00^{Bd} ±0,71	4,70 ^{Ae} ±0,99	3,50 ^{Af} ±0,71	2,50^{Ag} ±0,71	1,50^{Ag} ±0,71
220 MPa 25 ºC 5 dk	9,00 ^{Aa} ±0,00	8,55 ^{Ab} ±0,07	8,15^{Bb} ±0,49	6,25 ^{Ac} ±1,06	5,00^{Bd} ±0,71	4,50 ^{Bd} ±0,00	3,75 ^{Ae} ±1,06	2,00 ^{Af} ±0,00	1,00 ^{Af} ±0,00

Tablo 4.4.2. Soğukta (4ºC) depolama sırasında tekirin duyusal parametrelerinde (koku) meydana gelen değişimler

(Büyük harfler her kolondaki gruplar arası farkı, küçük harfler her satırdaki gruplar arası farkı ifade etmektedir.)

Depolama günleri	1	3	5	7	9	11	13	15	17
Kontrol	9,35 ^{Aa} ±0,21	8,00 ^{Ab} ±0,00	6,75 ^{Ac} ±1,06	4,85 ^{Ad} ±0,21	3,50 ^{Ae} ±2,12	3,50 ^{Ae} ±0,71	2,00 ^{Af} ±0,00	1,50^{Af} ±0,71	1,10 ^{Af} ±0,00
330 MPa 3ºC 5 dk	9,35 ^{Aa} ±0,21	8,75 ^{Ab} ±0,35	8,25 ^{Bb} ±0,35	6,25 ^{Bc} ±1,77	4,50 ^{Ad} ±0,71	3,25 ^{Ae} ±0,35	3,00 ^{Ae} ±0,00	3,00^{Be} ±0,71	1,00 ^{Af} ±0,00
220 MPa 25 ºC 5 dk	9,35 ^{Aa} ±0,21	7,50 ^{Ab} ±0,71	7,50 ^{Ab} ±0,71	5,75 ^{Bc} ±0,35	4,25 ^{Ad} ±1,06	3,75 ^{Ae} ±0,35	3,50 ^{Ae} ±0,71	2,75^{Bf} ±0,35	1,00 ^{Af} ±0,00

Tablo 4.4.3. Soğukta (4ºC) depolama sırasında tekirin renk değerlerinde (L*) meydana gelen değişimler

(Büyük harfler her kolondaki gruplar arası farkı, küçük harfler her satırdaki gruplar arası farkı ifade etmektedir.

Depolama günleri		1	3	5	7	9	11	13	15	17
L*	**Kontrol**	50,9^{Aa} ±1,5	51,9 ^{Aa} ±1,5	53,7 ^{Aa} ±2,2	53,6 ^{Aa} ±1,8	55,2 ^{Ab} ±1,7	57,9 ^{Ac} ±1,7	49,7 ^{Aa} ±1,1	62,5 ^{Ad} ±1,7	53,6^{Aa} ±1,0
	330 MPa 3ºC 5 dk	53,1 ^{Aa} ±0,7	54,2 ^{Aa} ±0,9	53,2 ^{Aa} ±1,6	55,3 ^{Ab} ±0,8	53,4 ^{Aa} ±2,0	59,3 ^{Ac} ±1,3	52,0 ^{Ba} ±0,3	57,7 ^{Bd} ±1,3	64,4^{Be} ±0,7
	220 MPa 25 ºC 5 dk	52,6 ^{Aa} ±0,3	53,9 ^{Aa} ±0,1	50,3 ^{Aa} ±0,5	55,9 ^{Ab} ±1,5	56,3 ^{Ac} ±1,5	55,9 ^{Ab} ±0,9	52,1 ^{Ba} ±0,6	56,6 ^{Bd} ±1,5	59,9 ^{Ce} ±0,5

Tablo 4.4.4. Soğukta (4ºC) depolama sırasında tekirin renk değerlerinde (a*) meydana gelen değişimler

(Büyük harfler her kolondaki gruplar arası farkı, küçük harfler her satırdaki gruplar arası farkı ifade etmektedir.)

Depolama günleri		1	3	5	7	9	11	13	15	17
a*	Kontrol	3,9^{Aa} ±0,5	4,5^{Ab} ±0,8	6,6^{Ac} ±0,7	4,2^{Ab} ±1,4	5,8^{Ad} ±1,2	5,3^{Ad} ±0,9	3,5^{Aa} ±0,5	3,8^{Aa} ±1,5	5,3^{Ad} ±0,9
	330 MPa 3 ºC 5 dk	2,2^{Ba} ±0,1	2,8^{Ba} ±0,1	5,1^{Bb} ±0,5	4,6^{Ac} ±1,0	4,3^{Bc} ±1,0	3,4^{Bd} ±0,4	3,5^{Ad} ±0,1	5,9^{Bb} ±1,4	3,2^{Bd} ±0,7
	220 MPa 25 ºC 5 dk	4,8^{Ca} ±0,5	5,6^{Ab} ±0,2	5,3^{Bb} ±0,6	4,0^{Aa} ±0,8	4,0^{Ba} ±0,5	3,2^{Bc} ±0,3	4,0^{Aa} ±0,3	5,4^{Bb} ±0,9	4,7^{Ca} ±0,5

Tablo 4.4.5. Soğukta (4ºC) depolama sırasında tekirin renk değerlerinde (b*) meydana gelen değişimler

(Büyük harfler her kolondaki gruplar arası farkı, küçük harfler her satırdaki gruplar arası farkı ifade etmektedir.)

Depolama günleri		1	3	5	7	9	11	13	15	17
b*	Kontrol	9,9^{Aa} ±1,0	10,8^{Aa} ±1,2	10,6^{Aa} ±0,9	10,9^{Aa} ±1,5	10,3^{Aa} ±1,3	13,0^{Ab} ±1,5	11,4^{Ac} ±0,9	14,5^{Ad} ±1,3	9,4^{Aa} ±1,3
	330 MPa 3 ºC 5 dk	9,6^{Aa} ±1,1	10,6^{Aa} ±1,2	10,2^{Aa} ±0,6	13,6^{Bb} ±0,9	10,4^{Aa} ±1,1	10,7^{Ba} ±1,4	11,1^{Ac} ±0,7	14,0^{Ab} ±1,3	8,3^{Ad} ±0,9
	220 MPa 25 ºC 5 dk	11,9^{Ba} ±1,2	12,2^{Ba} ±0,9	9,84^{Ab} ±1,1	11,7^{Aa} ±1,2	10,0^{Aa} ±1,3	10,3^{Ba} ±0,5	11,3^{Aa} ±0,9	11,5^{Ba} ±1,1	13,0^{Bc} ±0,4

Tablo 4.4.6. Soğukta (4ºC) depolama sırasında tekirin renk değerlerinde (ΔE) meydana gelen değişimler

(Büyük harfler her kolondaki gruplar arası farkı, küçük harfler her satırdaki gruplar arası farkı ifade etmektedir.)

Depolama günleri		1	3	5	7	9	11	13	15	17
ΔE	Kontrol	1,2^{Aa} ±0,9	1,6^{Aa} ±0,6	2,0^{Ab} ±0,5	2,3^{Ab} ±0,5	2,0^{Ab} ±0,5	1,9^{Aa} ±0,6	1,3^{Aa} ±0,2	2,0^{Ab} ±0,7	1,5^{Aa} ±0,5
	330 MPa 3 ºC 5 dk	2,8^{Ba} ±1,2	3,0^{Ba} ±0,8	2,1^{Aa} ±0,5	3,8^{Bb} ±0,7	3,0^{Ba} ±0,8	3,7^{Bb} ±0,5	2,3^{Ba} ±0,4	5,6^{Bc} ±0,7	11,1^{Bd} ±0,6
	220 MPa 25 ºC 5 dk	2,1^{Ba} ±0,3	2,7^{Ba} ±0,6	3,9^{Bb} ±0,4	2,3^{Aa} ±0,6	2,7^{Aa} ±0,6	4,0 ±0,7	2,2^{Ba} ±0,5	7,0^{Cc} ±0,8	7,3^{Cc} ±0,6

Tablo 4.4.7. Soğukta (4ºC) depolama sırasında tekirin pH, TVB-N, TMA-N ve TBA değerlerinde meydana gelen değişimler

(Büyük harfler her kolondaki gruplar arası farkı, küçük harfler her satırdaki gruplar arası farkı ifade etmektedir.

Depolama günleri		**1**	**3**	**5**	**7**	**9**	**11**	**13**	**15**	**17**
pH	**Kontrol**	6,4^{Aa} ±0,1	6,6^{Aa} ±0,1	6,6^{Aa} ±0,0	6,7^{Aa} ±0,1	6,7^{Aa} ±0,1	6,5^{Aa} ±0,1	7,1^{Ab} ±0,1	6,0^{Aa} ±0,1	6,5^{Aa} ±0,2
	330 MPa 3 ºC 5 dk	5,9^{Ba} ±0,0	6,2^{Ba} ±0,0	6,3^{Ba} ±0,0	6,7^{Ab} ±0,0	6,6^{Ab} ±0,1	6,3^{Aa} ±0,0	6,8^{Ab} ±0,0	6,1^{Aa} ±0,3	7,3^{Bc} ±0,3
	220 MPa 25 ºC 5 dk	6,2^{Aa} ±0,3	6,4^{Aa} ±0,1	6,5^{Aa} ±0,0	6,7^{Aa} ±0,0	6,5^{Aa} ±0,0	6,6^{Aa} ±0,0	7,0^{Ab} ±0,3	6,1^{Aa} ±0,0	6,7^{Aa} ±0,1

Depolama günleri		**1**	**3**	**5**	**7**	**9**	**11**	**13**	**15**	**17**
TVB-N (mg/100)	**Kontrol**	22,8^{Aa} ±0,3	23,7^{Aa} ±0,4	33,3^{Ab} ±0,6	47,3^{Ac} ±0,7	48,5^{Ac} ±0,3	46,7^{Ac} ±0,1	75,2^{Ad} ±0,0	84,4^{Ae} ±0,6	91,1^{Af} ±0,3
	330 MPa 3 ºC 5 dk	13,8^{Ba} ±0,2	14,9^{Ba} ±0,2	27,6^{Bb} ±0,8	37,7^{Bc} ±0,3	46,9^{Bd} ±0,5	51,3^{Be} ±0,8	83,8^{Bf} ±0,3	56,3^{Bg} ±0,1	51,2^{Be} ±0,8
	220 MPa 25 ºC 5 dk	19,9^{Ca} ±0,3	20,2^{Ca} ±0,1	34,3^{Ab} ±0,4	41,9^{Cc} ±0,7	51,3^{Ad} ±0,8	48,2^{Cc} ±0,1	71,3^{Ce} ±0,4	67,9^{Cf} ±0,6	56,8^{Cd} ±0,8

Depolama günleri		**1**	**3**	**5**	**7**	**9**	**11**	**13**	**15**	**17**
TMA-N (mg/100g)	**Kontrol**	2,8^{Aa} ±0,0	3,0^{Aa} ±0,0	5,2^{Ab} ±0,0	7,5^{Ac} ±0,1	5,7^{Ab} ±0,0	6,3^{Ad} ±0,0	10,2^{Ae} ±0,0	11,7^{Af} ±0,0	8,9^{Ag} ±0,1
	330 MPa 3 ºC 5 dk	0,8^{Ba} ±0,2	0,9^{Ba} ±0,0	3,8^{Bb} ±0,0	6,4^{Bc} ±0,0	6,9^{Bc} ±0,0	7,3^{Bd} ±0,0	10,0^{Ae} ±0,0	11,1^{Af} ±0,1	9,5^{Bg} ±0,0
	220 MPa 25 ºC 5 dk	1,9^{Ca} ±0,9	2,1^{Ca} ±0,0	4,6^{Cb} ±0,0	5,8^{Cc} ±0,0	6,9^{Bd} ±0,1	7,0^{Bd} ±0,0	11,7^{Ce} ±0,0	10,7^{Bf} ±0,1	9,7^{Bg} ±0,1

Depolama günleri		**1**	**3**	**5**	**7**	**9**	**11**	**13**	**15**	**17**
TBA (mg MDA/kg)	**Kontrol**	0,7^{Aa} ±0,0	0,8^{Ab} ±0,0	1,0^{Ac} ±0,0	1,1^{Ad} ±0,0	1,3^{Ae} ±0,0	0,8^{Ab} ±0,0	1,4^{Af} ±0,0	1,7^{Ag} ±0,1	1,1^{Ad} ±0,0
	330MPa 3ºC 5dk	0,5^{Ba} ±0,0	0,6^{Bb} ±0,0	0,9^{Bc} ±0,0	0,8^{Bd} ±0,0	0,9^{Bc} ±0,0	0,8^{Ad} ±0,0	0,8^{Bd} ±0,0	1,0^{Be} ±0,0	1,2^{Bf} ±0,0
	220 MPa 25 ºC 5 dk	0,5^{Ba} ±0,0	0,6^{Ba} ±0,0	0,7^{Cb} ±0,0	1,0^{Ac} ±0,0	1,0^{Cc} ±0,0	1,1^{Bd}± 0,0	1,0^{Cc} ±0,0	0,9^{Be} ±0,0	0,8^{Cf} ±0,1

Tablo 4.4.8. Soğukta (4ºC) depolama sırasında tekirin toplam aerobik mezofilik bakteri değerinde meydana gelen değişimler

(Büyük harfler her kolondaki gruplar arası farkı, küçük harfler her satırdaki gruplar arası farkı ifade etmektedir.

Depolama günleri		1	3	5	7	9	11	13	15	17
Mezofilik aerobik bakteri yükü log kob/g	**Kontrol**	3,77^{Aa} ±0,11	4,55^{Ab} ±0,03	4,55^{Ab} ±0,07	4,51^{Ab} ±0,04	4,57^{Ab} ±0,04	4,62^{Ab} ±0,19	5,97^{Ac} ±0,02	6,97^{Ad} ±0,07	8,16^{Ae} ±0,06
	330 MPa 3ºC 5 dk	<3^{Ba} ±0,00	<3^{Ba} ±0,00	4,26^{Ab} ±0,21	4,33^{Ab} ±0,10	4,24^{Ab} ±0,08	4,35^{Ab} ±0,07	4,52^{Bb} ±0,03	5,69^{Bc} ±0,00	6,25^{Bd} ±0,07
	220 MPa 25 ºC 5 dk	<3^{Ba} ±0,00	3,15^{Cb} ±0,21	4,17^{Ac} ±0,02	4,39^{Ac} ±0,13	4,33^{Ac} ±0,10	4,44^{Ac} ±0,06	4,63^{Bc} ±0,04	5,70^{Bd} ±0,07	6,47^{Be} ±0,00

Tablo 4.4.9. Soğukta (4ºC) depolama sırasında tekirin toplam psikrofilik aerobik bakteri değerinde meydana gelen değişimler

(Büyük harfler her kolondaki gruplar arası farkı, küçük harfler her satırdaki gruplar arası farkı ifade etmektedir.

Depolama günleri		1	3	5	7	9	11	13	15	17
Toplam psikrofilik aerobik bakteri yükü log kob/g	**Kontrol**	3,39^{Aa} ±0,12	4,04^{Ab} ±0,05	4,24^{Ab} ±0,08	4,57^{Ab} ±0,12	5,07^{Ac} ±0,01	6,29^{Ad} ±0,08	6,47^{Ad} ±0,18	6,80^{Ad} ±0,15	7,35^{Ae} ±0,07
	330 MPa 3 ºC 5 dk	<3^{Ba} ±0,00	3,50^{Ab} ±0,71	4,09^{Ac} ±0,13	4,35^{Ac} ±0,07	4,89^{Bc} ±0,01	5,02^{Bd} ±0,03	5,30^{Bd} ±0,14	5,70^{Bd} ±0,14	6,35^{Be} ±0,07
	220 MPa 25 ºC 5 dk	<3^{Ba} ±0,00	3,55^{Ab} ±0,49	4,17^{Ac} ±0,02	4,47^{Ac} ±0,10	4,96^{Bc} ±0,01	5,11^{Bd} ±0,04	5,60^{Bd} ±0,00	6,10^{Ae} ±0,14	6,55^{Be} ±0,21

Yukarıda detaylandırılan duyusal, kimyasal ve mikrobiyolojik analizler ışığında buzdolabı koşullarında (4ºC'de) saklanan basınçlanmamış tekirlerin raf ömrü 12 gün iken 250MPa/ 25ºC /5 dk uygulamasının ilave olarak 2 gün (toplamda 14 gün) ve 330 MPa/ 3ºC / 5dk uygulamasının ilave olarak 3 gün (toplamda 15 gün) raf ömrünü arttırdığı tesbit edilmiştir.

4.5. YSB uygulamasının alabalık *(Onchorynchus mykiss)* örneklerindeki kalite parametreleri ve amino asit miktarı üzerine etkileri

Kültür alabalığı *(Onchorynchus mykiss)* kullanılarak 7, 15 ve 25°C'de 5 ve 10 dakika süre ile 220, 250 ve 330 MPa kombinasyonlarında en iyi YHB şartlarını belirleyebilmek için renk, Trimetilamin azot (TMA-N), Tiyobarbitürik asit sayısı (TBA) ve serbest amino asit analizleri yapılmış ve kontrol grubuyla karşılaştırılmıştır (Tablo 4.5.1).

Tablo 4.5.1. Basınçlı alabalık örneklerinin renk değerlerindeki değişimler

(Büyük harfler her kolondaki gruplar arası farkı, küçük harfler her satırdaki gruplar arası farkı ifade etmektedir.)

Sıcaklık/Zaman		7°C/ 5 dk	7°C/ 10 dk	15°C/ 5dk	15°C/ 10 dk	25°C/ 5 dk	25°C/ 10 dk
L*	**Kontrol**	57.57^{Aa} ± 2.98	57.57^{Aa} ± 2.98	57.57^{Aa} ± 2.98	57.57^{Aa} ± 2.98	57.57^{Aa} ± 2.98	57.57^{Aa} ± 2.98
	220 MPa	65.34^{Ba} ± 2.42	67.01^{Ba} ± 1.08	67.62^{Ba} ± 2.72	62.76^{Ba} ±1.66	65.32^{Ba} ± 1.93	64.62^{Ba} ± 3.03
	250 MPa	65.81^{Ba} ± 4.62	69.71^{Ba} ± 0.64	66.16^{Ba} ± 0.81	69.42^{Ca} ± 0.43	72.96^{Cb} ± 2.43	68.30^{Ba} ± 1.53
	330 MPa	73.99^{Ba} ± 5.03	70.53^{Ba} ± 1.39	72.02^{Ba} ± 1.29	72.08^{Ca} ± 3.05	75.21^{Ca} ± 4.13	75.52^{Ca} ± 2.32
a*	**Kontrol**	2.88^{Aa} ± 0.91	2.88^{Aa} ± 0.91	2.88^{Aa} ± 0.91	2.88^{Aa} ± 0.91	2.88^{Aa} ± 0.91	2.88^{Aa} ± 0.91
	220 MPa	3.40^{Aa} ± 0.59	3.40^{Aa} ± 0.95	2.58^{Aa} ± 1.00	2.52^{Aa} ± 0.05	2.97^{Aa} ± 1.10	4.36^{Aa} ± 1.77
	250 MPa	2.47^{Aa} ± 1.80	1.25^{Bb} ± 0.34	2.84^{Aa} ± 0.44	2.02^{Aa} ± 1.14	2.22^{Aa} ± 1.59	2.84^{Aa} ± 0.69
	330 MPa	2.96^{Aa} ± 0.04	1.63^{Aa} ± 1.27	3.49^{Aa} ± 0.91	1.58^{Aa} ± 0.78	3.97^{Aa} ± 2.57	2.10^{Aa} ± 1.00
b*	**Kontrol**	14.97^{Aa} ± 5.37	14.97^{Aa} ± 5.37	14.97^{Aa} ± 5.37	14.97^{Aa} ± 5.37	14.97^{Aa} ± 5.37	14.97^{Aa} ± 5.37
	220 MPa	13.77^{Aa} ± 3.36	15.25^{Aa} ± 1.95	14.21^{Aa} ± 1.49	12.96^{Aa} ± 1.50	12.12^{Aa} ± 0.90	16.61^{Aa} ± 2.59
	250 MPa	12.24^{Aa} ± 0.71	14.59^{Aa} ± 1.00	14.54^{Aa} ± 3.42	14.13^{Aa} ± 0.76	14.82^{Aa} ± 2.27	13.43^{Aa} ± 2.21
	330 MPa	14.07^{Aa} ± 0.75	13.47^{Aa} ± 0.12	15.92^{Aa} ± 4.31	13.73^{Aa} ± 0.98	14.35^{Aa} ± 2.72	13.83^{Aa} ± 0.20
ΔE	**Kontrol**	-	-	-	-	-	-
	220 MPa	8.33 ± 0.86	9.00 ± 1.44	10.62 ± 4.31	5.63 ± 0.77	8.44 ± 0.69	6.73 ± 3.46
	250 MPa	9.41 ± 4.84	11.72 ± 0.55	9.70 ± 3.56	11.52 ± 0.30	15.74 ± 3.73	11.19 ± 1.41
	330 MPa	17.07 ± 5.95	12.69 ± 1.49	15.22 ± 4.79	14.14 ± 3.13	18.14 ± 2.85	17.46 ± 2.33

Basınçlanmış deniz ürünlerinin ΔE değerlerindeki değişim renkteki genel değişimin göstergesidir (Chevalier ve ark., 2001). Çalışma sonucunda elde edilen veriler ışığında alabalık için minimum ΔE değerlerinin 220 MPa/15-25ºC/10 dk, 220 MPa/7ºC/5-10 dk ve 250 MPa/7ºC/5 dk kombinasyonlarında elde edildiği görülmüştür. Literatürde basınçlanmış sazan için toplam renk değişimi 140 MPa/4 ºC/15 ve 30 dk ve 200 MPa/4 ºC/30 dk için sırasıyla 6.6, 8.6 ve 24.3 olarak verilmiştir (Sequeira- Munoz ve ark., 2006); 100 MPa/4 ºC /15 ve 30 dk ve 200 MPa/4 ºC /15 ve 30 dk basınçlanmış kalkan filetoları için toplam renk değişimlerini sırasıyla 5.9, 6.3, 20.3 ve 24.3 olarak vermiştir (Chevalier ve ark., 2001).

Tablo 4.5.2. Basınçlı alabalık örneklerinin TBA içeriğindeki değişimler

(Büyük harfler her kolondaki gruplar arası farkı, küçük harfler her satırdaki gruplar arası farkı ifade etmektedir.)

Sıcaklık/Zaman		7 °C/ 5 dk	7 °C/ 10 dk	15 °C/ 5 dk	15°C/ 10 dk	25 °C/ 5 dk	25°C/ 10 dk
TBA (mg MDA/kg)	**Kontrol**	2.77 ^{Aa} ± 0.15	2.77 ^{Aa} ± 0.14	2.77 ^{Aa} ± 0.15	2.77 ^{Aa} ± 0.14	2.77 ^{Aa} ± 0.15	2.77 ^{Aa} ± 0.14
	220 MPa	2.34 ^{Aa} ± 0.07	2.23 ^{Bb} ± 0.02	2.46 ^{Aa} ± 0.35	1.96 ^{Ba} ± 0.09	2.52 ^{Aa} ± 0.31	2.06 ^{Bb} ± 0.25
	250 MPa	2.40^{Aa} ± 0.43	2.18 ^{Bb} ± 0.03	2.36 ^{Aa} ± 0.42	2.30 ^{Aa} ± 0.46	2.39 ^{Aa} ± 0.54	1.98 ^{Bb} ± 0.42
	330 MPa	2.31^{Aa} ± 0.30	2.30 ^{ABa} ± 0.32	2.44 ^{Aa} ± 0.25	2.18 ^{Ba} ± 0.29	2.30 ^{Aa} ± 0.38	2.00 ^{Ba} ± 0.42

Tablo 4.5.3. Basınçlı alabalık örneklerinin TMA içeriğindeki değişimler

(Büyük harfler her kolondaki gruplar arası farkı, küçük harfler her satırdaki gruplar arası farkı ifade etmektedir.)

Sıcaklık/Zaman		7 °C/ 5 dk	7 °C/ 10 dk	15 °C/ 5 dk	15°C/ 10 dk	25°C/ 5 dk	25°C/ 10 dk
TMA-N mg/100g	**Kontrol**	1.60 ^{Aa} ± 0.44	1.60 ^{Aa} ± 0.44	1.60 ^{Aa} ± 0.44	1.60 ^{Aa} ± 0.44	1.60 ^{Aa} ± 0.44	1.60 ^{Aa} ± 0.44
	220 MPa	1.44^{Aa} ± 0.34	1.59 ^{Aa} ± 0.07	1.15 ^{Aa} ± 0.28	1.74 ^{Aa} ± 0.09	1.12 ^{Aa} ± 0.57	0.50 ^{Bb} ± 0.14
	250 MPa	1.51^{Aa} ± 0.18	0.48 ^{Bb} ± 0.14	0.50 ^{Bb} ± 0.03	2.05 ^{Ac} ± 0.06	1.15 ^{Bd} ± 0.06	0.35 ^{Bb} ± 0.11
	330 MPa	1.52^{Aa} ± 0.13	1.81^{Aa} ± 0.53	0.97 ^{Bb} ± 0.18	1.73 ^{Aa} ± 0.11	1.17 ^{Bb} ± 0.07	0.95^{Cb} ± 0.06

Tablo 4.5.4. Basınçlı alabalık örneklerinin serbest amino asit miktarındaki değişimler

Amino asit (mg/ 100g)	C	220 MPa, 7 ºC, 5 dk	220 MPa, 7ºC, 10 dk	250 MPa, 7ºC, 5 dk	250 MPa, 7ºC, 10 dk	330 MPa, 7ºC, 5 dk	330 MPa, 7ºC, 10 dk	220 MPa, 15ºC, 5 dk	220 MPa, 15ºC, 10 dk	250 MPa, 15ºC, 5 dk	250 MPa, 15ºC, 10 dk	330 MPa, 15ºC, 5 dk	330 MPa, 15ºC, 10 dk	220 MPa, 25ºC, 5 dk	220 MPa, 25ºC, 10 dk	250 MPa, 25ºC, 5 dk	250 MPa, 25ºC, 10 dk	330 MPa 25C 5 dk	330 MPa 25C 10 dk
Lys	2111.11 ±15.99	1940.78 ±8.90	1927.4 ±2.15	1877.42 ±8.08	1932.67 ±8.17	1949.68 ±7.27	2076.19 ±18.31	1763.0 ±9.06	1812.46 ±32.94	1871.93 ±10.42	1738.64 ±6.12	1527.93 ±6.41	1931.69 ±17.64	1833.94 ±8.87	2274.23 ±28.33	2239.56 ±0.85	2038. ±5.14	2470. ±7.02	2242.46 ±5.19
Meth	682.62 ±1.73	700.83 ±2.04	786.32 ±2.17	715.19 ±0.63	622.70 ±2.87	758.37 ±5.67	831.99 ±6.18	728.18 ±7.55	711.38 ±7.66	726.95 ±11.88	687.09 ±0.02	718.02 ±2.02	728.84 ±5.12	644.89 ±1.37	835.70 ±12.14	888.44 ±9.10	746.1 ±3.50	957.3 ±2.20	734.52 ±1.92
Thre	971.32 ±3.11	931.94 ±9.33	930.31 ±4.30	901.27 ±3.75	916.21 ±3.11	1064.48 ±8.74	989.88 ±4.16	937.70b ±1.21	876.75 ±20.74	871.69 ±1.17	900.62 ±4.61	920.63 ±1.31	888.51 ±6.93	847.30 ±2.45	1122.28 ±1.80	1080.27 ±9.88	1079. ±0.10	1179. ±0.05	1006.79 ±0.65
Isoleu	1131.39 ±8.12	1188.24 ±9.69	1142.69 ±0.65	1056.67 ±8.50	1041.78 ±15.97	1309.09 ±2.43	1269.36 ±14.01	1119.17 ±2.26	1070.84 ±10.94	1038.95 ±2.66	1038.70 ±17.43	1102.29 ±0.80	1138.55 ±11.22	1059.56 ±4.27	1304.49 ±8.81	1202.94 ±5.63	1232. ±1.80	1374. ±5.30	1194.99 ±0.24
Leu	1692.22 ±5.81	1670.97 ±4.43	1636.54 ±0.65	1547.64 ±6.66	1535.55 ±11.93	1795.33 ±3.38	1773.65 ±13.19	1607.21 ±11.32	1516.40 ±9.14	1523.69 ±10.74	1490.88 ±1.10	1566.94 ±5.87	1599.63 ±2.81	1519.58 ±7.26	1901.84 ±0.75	1836.56 ±0.08	1807. ±3.65	2031. ±4.39	1792.72 ±6.84
Phen	977.81 ±2.84	1000.58 ±3.37	985.44 ±3.66	924.49 ±7.29	909.72 ±9.68	1107.71 ±4.76	1051.85 ±0.23	946.43 ±4.78	887.31 ±1.28	911.42 ±4.30	909.11 ±1.76	1064.26 ±1.60	960.68 ±5.03	916.86 ±4.90	1128.81 ±3.01	1101.78 ±2.65	1040. ±6.25	1215. ±1.24	1067.24 ±1.40
Val	1263.64 ±15.81	1349.64 ±8.87	1283.30 ±4.26	1165.83 ±0.14	1153.22 ±11.22	1510.94 ±3.60	1417.81 ±18.95	1256.51 ±2.57	1208.95 ±28.36	1146.29 ±4.72	1164.85 ±14.54	1234.34 ±3.55	1285.40 ±10.21	1195.72 ±6.41	1423.10 ±7.29	1320.20 ±6.80	1410. ±4.13	1495. ±2.85	1336.75 ±0.12
His	625.89 ±2.289	640.49 ±1.35	637.90 ±6.99	588.17 ±7.77	594.66 ±6.11	813.52 ±6.09	686.07 ±4.80	608.960 ±4.06	588.41 ±5.25	552.95 ±0.42	602.39 ±1.89	671.49 ±6.36	634.84 ±0.15	593.40 ±3.16	729.49 ±3.10	693.55 ±1.32	773.3 ±12.2	779.1 ±1.35	675.93 ±3.35
Ser	833.25 ±0.65	889.55 ±2.75	852.23 ±6.39	832.39 ±2.69	794.64 ±0.084	1649.72 ±4.72	813.81 ±1.05	846.37 ±1.44	736.65 ±6.25	794.82 ±4.97	850.77 ±6.63	787.01 ±5.87	764.02 ±4.09	775.57 ±0.91	989.09 ±3.13	944.76 ±1.98	1104. ±6.59	1018. ±8.92	890.29 ±5.01
Arg	1530.07 ±5.90	1465.71 ±2.08	1429.22 ±8.94	1342.70 ±1.70	1351.70 ±21.34	1428.51 ±14.30	1500.33 ±6.77	1336.29 ±0.41	1311.66 ±12.99	1285.11 ±6.54	1330.84 ±3.27	1491.81 ±2.61	1404.07 ±19.30	1353.92 ±5.50	1729.04 ±3.04	1586.12 ±6.76	1807. ±2.61	1751. ±3.41	1580.42 ±9.57
Cys	130.64 ±0.09	99.75 ±0.77	111.17 ±0.01	99.170 ±2.15	129.54 ±1.20	119.45 ±1.02	113.23 ±0.016	79.66 ±0.46	91.323 ±3.285	112.27 ±2.03	88.66 ±0.26	136.96 ±2.02	119.42 ±2.18	128.26 ±0.10	167.53 ±2.01	130.33 ±1.23	209.3 ±2.54	177.0 ±1.35	130.67 ±1.28
Tyr	808.19 ±5.84	833.34 ±0.02	817.79 ±2.66	767.20 ±1.76	750.40 ±0.55	985.03 ±3.18	867.26 ±0.38	803.10 ±0.94	764.11 ±1.48	760.89 ±2.01	801.62 ±8.49	892.94 ±2.23	800.82 ±0.48	769.92 ±6.72	948.24 ±1.48	920.16 ±10.17	969.0 ±1.19	984.7 ±0.69	871.57 ±7.34
Ala	1065.84 ±12.11	1264.58 ±8.02	1226.49 ±1.94	1125.87 ±1.71	989.20 ±2.14	1359.69 ±10.86	1354.55 ±7.64	1165.36 ±1.25	1150.51 ±24.83	1109.70 ±5.30	1077.78 ±16.50	965.86 ±4.29	1215.58 ±17.90	1080.32 ±10.06	1384.62 ±26.52	1346.62 ±0.57	1764. ±0.51	1506. ±3.95	1108.32 ±3.39
Asp	2318.71 ±10.16	2019.87 ±8.46	2109.25 ±0.18	2019.71 ±0.62	2110.44 ±4.72	2196.74 ±14.63	2269.03 ±30.41	1863.17 ±5.69	1889.40 ±28.41	1953.88 ±0.19	1908.01 ±26.01	1555.94 ±5.67	2057.73 ±10.92	1911.45 ±11.07	2471.93 ±57.343	2391.50 ±19.83	2028. ±7.56	2618. ±34.5	2463.15 ±3.23
Glut	3276.39 ±10.65	2837.75 ±5.55	2923.99 ±6.39	2788.76 ±12.59	2950.38 ±1.44	2836.94 ±7.29	3140.60 ±36.47	2703.33 ±2.25	2708.32 ±4.04	2784.90 ±34.14	2634.44 ±16.29	2288.42 ±4.33	2835.25 ±17.39	2680.10 ±11.37	3457.67 ±47.134	3311.94 ±11.80	2993. ±4.59	3663. ±5.90	3430.31 ±4.05
Gly	1014.10 ±3.84	1224.08 ±7.83	1112.70 ±0.01	996.21 ±1.75	936.17 ±4.32	1484.32 ±4.02	1111.58 ±3.74	989.08 ±8.51	945.74 ±11.85	914.49 ±2.50	1032.30 ±9.55	1128.14 ±1.66	1077.24 ±5.73	1008.26 ±5.17	1166.87 ±12.194	1154.06 ±3.10	1524. ±0.94	1239. ±1.50	1110.01 ±3.21
Prol	689.36 ±0.64	730.91 ±6.06	669.63 ±13.14	610.89 ±7.12	614.28 ±4.39	734.32 ±1.02	709.31 ±0.50	662.31 ±8.18	627.78 ±0.96	603.58 ±4.65	629.26 ±3.64	641.45 ±0.87	642.48 ±10.25	604.08 ±4.77	751.602 ±1.403	701.32 ±10.19	733.2 ±1.94	773.7 ±0.19	728.00 ±2.14
Total	21559.3	21242.1	21249.6	19726.5	19733.9	23598.3	22491.2	19805.8	19317.2	19312.9	19319.9	19018.2	20552.3	19367.4	24207.9	23252.6	23899	25683	22903.0

Alabalık yüksek miktarlarda glutamic asit, aspartik asit ve lisin içermektedir. YSB işleminden sonra amino asit içerikleri dalgalanmalar göstermiş ve serbest amino asitler artmış ve-veya azalmıştır. YSB uygulaması sırasında basınç, sıcaklık ve zamana bağlı olarak protein denatürasyonu gerçekleşmiştir. Ancak zaman zaman proteinler 300 MPa'ya kadar basınç altında denatüre olabildikleri gibi geri dönüşümlü olarak çökelebilirler (Okpalo ve diğ., 2010). İşte amino asit içeriğindeki bu değişimler balığın koku ve tadında ve kalite parametrelerinde-özellkile saklama sırasında- olumsuz etki yapabilir. Literatüde çok kapsamlı olarak çalışılmayan bu konunun, YHB işlemi uygulanan deniz ürünlerinde takip edilmesi gerektiği sonuçlarımızdan anlaşılmaktadır.

Alabalık örnekleriyle yapılan çalışma sonucunda, çalışılan deneysel parametrelerin fiziksel (renk) ve kimyasal (TMA ve TBA) analizleri en uygun YHB koşullarının 220 ve 250 MPa düzeyindeki -göreceli-düşük basınçlarda elde edildiği; basıncın 220 MPa olarak seçilmesi halinde kombinasyonun 7-15-25'^{o}C'lerde 10 dk; basıncın 250 MPa seçilmesi halinde ise sadece 7 ve 15'°C'lerde 5 dk kombinasyonunun uygun olduğu sonucuna varılmıştır. 330 MPa ve üzerindeki basınç uygulamalarının –çalışılan parametreler ışığında- alabalık basınçlanmasına uygun olmadığı görülmüştür.

4.6. YSB uygulamasının istavrit *(Trachurus trachurus)* örneklerindeki fizikokimyasal parametreler üzerine etkileri

İstavrit *(Trachurus trachurus)* kullanılarak 7, 15 ve 25°C'de 5 ve 10 dakika süre i le 220, 250 ve 330 MPa kombinasyonlarında en iyi YHB şartlarını belirleyebilmek için renk, Trimetilamin azot (TMA-N), Tiyobarbitürik asit sayısı (TBA) ve serbest amino asit analizleri yapılmış ve kontrol grubuyla karşılaştırılmıştır (Tablo 4.6.1).

Tablo 4.6.1. Basınçlı istavrit örneklerinin renk değerlerindeki değişimler

(Büyük harfler her kolondaki gruplar arası farkı, küçük harfler her satırdaki gruplar arası farkı ifade etmektedir.)

Sıcaklık/Zaman		**7°C/ 5 dk**	**7°C/ 10 dk**	**15°C/ 5dk**	**15°C/ 10 dk**	**25°C/ 5 dk**	**25°C/ 10 dk**
L*	**Kontrol**	54.05 Aa ±1.67[a]	54.05 Aa ±1.67	54.05 Aa ±1.67	54.05 Aa ±1.67	54.05 Aa ±1.67	54.05 Aa ±1.67
	220 MPa	49.97 Ba ±2.14	59.22 Bb ±1.36	52.29 Aa ±3.83	54.06 Aa ±0.93	51.99 Aa ±4.20	55.42 Aa ±2.63
	250 MPa	54.75 Aa ±3.00	59.66 Ba ±1.95	57.72 Aa ±2.49	53.42 Aa ±1.59	63.16 Bb ±3.93	55.01 Aa ±2.65
	330 MPa	62.70 Ca ±5.31	59.50 Ba ±1.77	65.74 Ba ±3.04	58.19 Bb ±0.72	68.91 Bb ±3.27	59.34 Ab ±1.40
a*	**Kontrol**	2.75 Aa ±0.58	2.75 Aa ±0.58	2.75 Aa ±0.58	2.75 Aa ±0.58	2.75 Aa ±0.58	2.75 Aa ±0.58
	220 MPa	2.88 Aa ±0.75	−0.06 Bb ±0.83	2.51 Aa ±0.64	0.07 Bb ±0.68	1.90 Aa ±1.13	1.04 Bb ±0.45
	250 MPa	1.21 Aa ±1.94	0.06 Bb ±0.47	0.62 Ba ±1.48	1.00 Ba ±0.28	1.36 Aa ±1.51	0.50 Ba ±1.46
	330 MPa	3.07 Aa ±0.89	0.44 Bb ±0.68	2.81 Aa ±0.90	0.11 Bb ±0.42	2.87 Aa ±1.69	−0.19 Bb ±0.33
b*	**Kontrol**	8.89 Aa ±0.52	8.89 Aa ±0.52	8.89 Aa ±0.52	8.89 Aa ±0.52	8.89 Aa ±0.52	8.89 Aa ±0.52
	220 MPa	4.89 Ba ±1.71	7.15 Aa ±2.43	5.73 Aa ±2.40	6.84 Aa ±0.57	5.87 Aa ±2.00	5.56 Ba ±0.60
	2500 MPa	5.45 Aa ±3.40	8.50 Aa ±0.44	5.12 Aa ±3.03	5.99 Aa ±1.06	7.40 Aa ±2.69	5.84 Aa ±2.80
	330 MPa	7.88 Aa ±1.44	7.76 Aa ±1.23	8.14 Aa ±0.64	8.30 Aa ±1.95	6.53 Aa ±1.15	5.76 Aa ±1.31
ΔE	**Kontrol**	–	–	–	–	–	–
	220 MPa	4.02 ±1.09	8.66 ±1.28	4.27 ±1.31	4.49 ±1.12	7.34 ±3.31	5.77 ±1.42
	250 MPa	6.84 ±4.78	8.59 ±1.96	9.42 ±2.10	6.33 ±0.44	15.31 ±4.69	5.87 ±2.57
	330 MPa	15.58 ±9.31	8.48 ±1.34	18.45 ±6.29	7.43 ±0.56	20.82 ±6.09	9.04 ±0.84

Basınçlanmış deniz ürünlerinin ΔE değerlerindeki değişim renkteki genel değişimin göstergesidir (Chevalier ve diğ., 2001). Çalışma sonucunda elde edilen veriler ışığında istavrit için minimum ΔE değerlerinin 220 MPa/7-15ºC/5 dk, 220 MPa/15-25ºC/10 dk, 250 MPa/25ºC/10 dk ve 250 MPa/7ºC/5 dk kombinasyonlarında elde edildiği görülmüştür.

İstavritte TBA, TMA ve serbest amino asit değişimleri Tablo 4.6.2-4.6.3 ve 4.6.4'de verilmiştir.

Tablo 4.6.2. Basınçlı istavrit örneklerinin TBA içeriğindeki değişimler

(Büyük harfler her kolondaki gruplar arası farkı, küçük harfler her satırdaki gruplar arası farkı ifade etmektedir.)

Sıcaklık/Zaman		**7 °C/ 5 dk**	**7 °C/ 10 dk**	**15 °C/ 5 dk**	**15°C/ 10 dk**	**25 °C/ 5 dk**	**25°C/ 10 dk**
TBA mg MDA/kg	**Kontrol**	2.98^{Aa} ± 0.38	2.98^{Aa} ± 0.38	2.98^{Aa} ± 0.38	2.98^{Aa} ± 0.38	2.98^{Aa} ± 0.38	2.98^{Aa} ± 0.38
	220 MPa	4.01^{Aa} ± 0.65	3.16^{Aa} ± 1.38	2.69^{Aa} ± 0.35	4.00^{Ba} ± 0.07	3.16^{Aa} ± 0.76	2.70^{Aa} ± 0.25
	250 MPa	4.50^{Aa} ± 1.24	3.58^{Aa} ± 0.01	2.77^{Aa} ± 0.71	2.96^{Aa} ± 0.01	2.85^{Aa} ± 1.04	2.88^{Aa} ± 0.22
	330 MPa	3.48^{Aa} ± 0.58	3.16^{Aa} ± 0.32	2.79^{Aa} ± 1.30	2.31^{Ca} ± 0.18	2.82^{Aa} ± 0.99	2.40^{Aa} ± 0.16

Basınçlanmış ve kontrol örneklerin TBA değişimleri istatistiksel olarak önemsiz ($p>0.05$) bulunmuştur.

Tablo 4.6.3. Basınçlı istavrit örneklerinin TMA içeriğindeki değişimler

(Büyük harfler her kolondaki gruplar arası farkı, küçük harfler her satırdaki gruplar arası farkı ifade etmektedir.)

Sıcaklık/Zaman		**7 °C/ 5 dk**	**7 °C/ 10 dk**	**15 °C/ 5 dk**	**15°C/ 10 dk**	**25°C/ 5 dk**	**25°C/ 10 dk**
TMA-N mg/100g	**Kontrol**	2.58^{Aa} ± 0.59	2.58^{Aa} ± 0.59	2.58^{Aa} ± 0.59	2.58^{Aa} ± 0.59	2.58^{Aa} ± 0.59	2.58^{Aa} ± 0.59
	220 MPa	2.45^{Aa} ± 0.35	2.37^{Aa} ± 0.17	1.99^{Aa} ± 0.56	2.11^{Aa} ± 0.22	2.08^{Aa} ± 0.42	1.21^{Bb} ± 0.39
	250 MPa	1.98^{Aa} ± 0.28	2.13^{Aa} ± 0.19	2.78^{Aa} ± 1.27	1.59^{Aa} ± 0.38	2.16^{Ab} ± 0.53	1.49^{Ba} ± 0.25
	330 MPa	1.90^{Aa} ± 1.23	1.53^{Bb} ± 0.07	2.26^{Aa} ± 0.65	2.33^{Aa} ± 0.23	2.89^{Aa} ± 0.18	1.37^{Bb} ± 0.35

Tablo 4.6.4. Basınçlı istavrit örneklerinin serbest amino asit miktarındaki değişimler

Amino asit (mg/ 100g)	C	220 MPa. 7 ºC. 5 dk	220 MPa. 7ºC. 10 dk	250 MPa. 7ºC. 5 dk	250 MPa. 7ºC. 10 dk	330 MPa. 7ºC. 5 dk	330 MPa. 7ºC. 10 dk	220 MPa. 15ºC. 5 dk	220 MPa. 15ºC. 10 dk	250 MPa. 15ºC. 5 dk	250 MPa. 15ºC. 10 dk	330 MPa. 15ºC. 5 dk	330 MPa. 15ºC. 10 dk	220 MPa. 25ºC. 5 dk	220 MPa. 25ºC. 10 dk	250 MPa. 25ºC. 5 dk	250 MPa. 25ºC. 10 dk	330 MPa 25C 5 dk	330 MPa 25C 10 dk
Lys	1714 ±0.60	**1786 ±20.23**	1950 ±6.52	**1817 ±15.71**	1543 ±4.66	2060 ±13.76	**1782 ±12.37**	**1720 ±2.85**	1828 ±10.12	2026 ±26.74	1897 ±19.38	1866 ±1.17	1826 ±11.42	**1755 ±20.40**	1867 ±4.83	1549 ±2.18	**1723 ±29.39**	1832 ±1.98	1780 ±0.20
Meth	549 ±0.43	603 ±0.73	613 ±0.70	**548 ±2.16**	384 ±3.15	741 ±8.63	**555 ±2.47**	**557 ±1.58**	537 ±0.53	589 ±1.30	605 ±3.99	625 ±0.38	634 ±3.56	**568 ±1.94**	773 ±2.94	673 ±0.83	640 ±0.90	650 ±3.01	423 ±0.67
Thre	794 ±0.63	**799 ±3.34**	914 ±2.22	837 ±4.12	**773 ±2.44**	932 ±3.50	826 ±2.77	782 ±1.64	874 ±2.85	879 ±2.21	**814 ±44.00**	**809 ±2.54**	827 ±1.46	753 ±0.89	916 ±7.30	757 ±3.42	**782 ±7.05**	876 ±0.59	**834 ±5.69**
Isoleu	902 ±0.20	**905 4.06**	1043 ±2.69	**936 ±4.94**	816 ±6.12	1070 ±2.82	**928 ±8.75**	**903 ±10.02**	**912 ±9.09**	1017 ±10.69	980 ±5.61	961 ±2.55	**946 ±9.10**	**888 ±4.46**	1073 ±7.72	**948 ±13.69**	**899 ±4.27**	1040 ±3.88	**950 ±6.50**
Leu	1338 ±0.18	**1363 ±6.15**	1553 ±1.44	1430 ±16.97	**1172 ±6.71**	1605 ±2.80	**1373 ±14.97**	**1360 ±14.98**	1429 ±1.37	1572 ±7.87	1466 ±3.89	1465 ±13.72	**1419 ±12.26**	**1336 ±8.40**	1622 ±4.35	**1419 ±25.61**	**1370 ±25.00**	1514 ±4.02	1441 ±11.22
Phen	759 ±0.21	828 ±4.40	890 ±7.01	831 ±4.20	855 ±3.32	920 ±4.56	793 ±0.87	**786 ±4.05**	807 ±2.28	865 ±2.68	826 ±0.65	**792 ±10.75**	833 ±3.70	**791 ±11.82**	879 ±0.41	**765 ±0.98**	803 ±3.84	801 ±0.72	819 ±5.53
Val	953 ±0.25	**939 ±3.84**	1115 ±9.79	1007 ±5.47	1013 ±2.10	1130 ±13.65	**978 ±5.99**	985 ±1.96	**1010 ±28.36**	1094 ±1.28	**997 ±13.28**	**997 ±12.70**	**984 ±7.57**	**916 ±5.33**	1195 ±0.24	1030 ±2.03	**946 ±3.65**	1162 ±10.86	1010 ±2.79
His	649 ±0.44	581 ±0.44	699 ±3.05	613 ±2.09	563 ±4.84	**660 ±1.62**	602 ±1.41	606 ±3.73	618 ±1.31	614 ±2.39	729 ±0.70	**648 ±4.16**	**618 ±3.14**	602 ±1.76	719 ±3.22	**654 ±2.44**	500 ±0.53	723 ±3.45	592 ±5.78
Ser	761 ±0.15	731 ±0.49	8322 ±2.25	813 ±4.91	819 ±2.90	868 ±2.01	885 ±4.92	789 ±1.71	1017 ±3.74	836 ±2.32	**770 ±1.95**	**764 ±4.85**	870 ±2.57	701 ±6.28	965 ±3.35	**739 ±8.27**	**741 ±3.71**	881 ±5.03	785 ±1.11
Arg	1522 ±0.93	1411 ±2.49	1773 ±1.07	1579 ±7.04	1701 ±8.03	1631 ±2.78	**1523 ±7.41**	**1630 ±0.52**	1939 ±8.93	1631 ±2.96	1639 ±3.28	1588 ±0.94	**1518 ±7.92**	1391 ±4.10	1742 ±14.12	1409 ±3.29	**1478 ±11.82**	1538 ±0.01	1775 ±2.25
Cys	176 ±3.91	161 ±2.85	113 ±1.32	118 ±1.99	**155 ±0.12**	**160 ±0.35**	104 ±1.02	126 ±0.46	110 ±1.79	100 ±0.12	142 ±1.31	107 ±2.22	123 ±1.73	**150 ±0.01**	**180 ±0.20**	**160 ±2.44**	128 ±0.24	**174 ±0.66**	136 ±0.01
Tyr	662 ±0.94	**685 ±3.77**	754 ±2.14	717 ±4.73	706 ±3.75	799 ±0.04	710 ±2.29	**671 ±3.10**	**702 ±10.67**	720 ±0.51	766 ±6.15	**668 ±2.92**	**697 ±5.47**	**670 ±3.69**	876 ±6.24	765 ±3.96	**674 ±7.00**	818 ±8.29	**669 ±3.42**
Ala	952 ±0.66	1053 ±11.07	1386 ±5.52	1132 ±2.30	1151 ±17.05	1281 ±15.53	1088 ±2.00	1280 ±11.06	1404 ±14.95	1188 ±3.01	1044 ±8.07	1081 ±2.91	1036 ±1.15	**944 ±3.05**	1093 ±0.61	764 ±7.19	1057 ±2.92	1002 ±4.81	1066 ±1.18
Asp	1761 ±0.11	1853 ±7.25	2172 ±11.17	1898 ±1.22	1673 ±9.68	2214 ±8.17	1914 ±6.19	1959 ±4.71	2027 ±12.25	2129 ±2.52	1913 ±4.33	1966 ±13.83	**1835 ±10.50**	**1749 ±4.51**	**1812 ±7.14**	1477 ±0.76	**1799 ±9.97**	**1791 ±9.14**	1902 ±1.09
Glut	2597 ±0.47	**2711 ±16.53**	3202 ±23.67	**2871 ±37.94**	**2521 ±13.27**	3267 ±18.97	2764 ±0.73	2855 ±6.31	2952 ±23.84	3065 ±23.44	**2733 ±22.96**	2923 ±3.59	2744 ±0.63	**2645 ±53.92**	2719 ±5.00	2212 ±23.66	**2693 ±12.79**	**2669 ±9.69**	2779 ±5.73
Gly	1001 ±0.33	841 ±6.34	1417 ±8.25	**999 ±0.73**	1880 ±9.24	1049 ±1.67	911 ±2.48	1472 ±10.54	1786 ±13.27	932 ±2.50	747 ±2.19	911 ±0.00	1101 ±3.44	795 ±2.06	1630 ±4.96	1055 ±1.21	**1005 ±9.14**	1104 ±2.94	1112 ±4.81
Prol	591 ±3.20	575 ±4.86	891 ±1.36	653 ±0.13	931 ±4.64	718 ±2.71	**577 ±6.60**	885 ±0.03	976 ±1.55	**593 ±4.89**	**538 ±3.61**	**576 ±5.99**	**644 ±28.80**	520 ±4.41	757 ±2.37	529 ±4.20	**580 ±2.79**	**605 ±7.09**	680 ±5.72

Balık ürünleri içerdikleri amino asitlere ve proteinlere bağlı olarak yüksek besin değerine sahiptirler. Bu ürünlerin amino asit içerikleri hem diyet hem de duyusal ve kalite kabul özelliklerini direk etkilemeleri bakımından önem arzetmektedir. Buna bağlı olarak farklı araştırmacılar deniz ürünlerine uygulanan işlemler sonucunda oluşan amino asit değişimlerini takip etmektedirler. Literatürde birçok deniz ürününün amino asit kompozisyonu verilmiş-iyice çalışılmış olmasına rağmen YSB işlemi sonrasında oluşan değişimlerle ilgili sınırlı bilgi verilmektedir (Erkan ve diğ., 2010).

5. Sonuçlar

Projede elde edilen sonuçlar aşağıda özetlenmiştir:

A) <u>Dumanlanmış somon:</u>

i) Farklı YSB kombinasyonları uygulanmış (220, 250 ve 330 MPa'da 3, 7, 15 ve 25℃'da 5 ve 10 dakika) dumanlanmış somon balığı örneklerinde renk, TMA-N ve TBA analiz sonuçları toplu olarak değerlendirildiğinde (kontrol örneğinin değerlerine yakın veya daha düşük L*, a*, b*, TMA-N ve TBA değerleri baz alınarak) soğuk dumanlanmış somon için 3ºC/5dk/250 MPa ve 25ºC/10dk/250MPa YHB uygulamasının en iyi kombinasyonlar olduğu tespit edilmiştir.

ii) 2ºC'de 8 hafta süren raf ömrü çalışmaları sonucunda basınçlanmamış dumanlanmış somon balıklarının 6 hafta sonucunda raf ömrünü tamamladıkları ancak bu iki YSB kombinasyonu sonucu çalışılan örneklerin buna ilave olarak 2 haftalık raf ömrü artışı sağladığı gözlenmiştir.

iii) Elde edilen veriler ışığında dumanlanmış somon filetolarına YSB işlemi uygulanmasının (çalışılan koşullarda) çalışılan kalite parametrelerini olumsuz olarak etkilemeden, güvenli raf ömrü artırımı sağladığı belirlenmiştir.

B) <u>Tekir (*Mullus surmutelus*):</u>

i) YSB deney deseninde (3, 7, 15 ve 25℃'de 5 ve 10 dakika süre 220, 250 ve 330 MPa) yağlı balık türü olan tekir (Mullus surmutelus) kullanılarak en iyi YHB şartlarını belirleyebilmek için renk, TMA-N ve TBA analiz sonuçları toplu olarak değerlendirildiğinde (kontrol örneğinin değerlerine yakın veya daha düşük L*, a*, b*, TMA-N ve TBA değerleri baz alınarak) tekir için 330 MPa/ 3ºC / 5dk ve 250MPa/ 25ºC/5 dk YHB uygulamasının en iyi kombinasyonlar olduğu tespit edilmiştir.

ii) Tekir için yukarıda detaylandırılan duyusal, kimyasal ve mikrobiyolojik analizler ışığında buzdolabı koşullarında (4ºC'de) saklanan basınçlanmamış tekirlerin raf ömrü 12 gün iken 250MPa/ 25ºC /5 dk uygulamasının ilave olarak 2 gün ($p<0.05$) (toplamda 14 gün) ve 330 MPa/ 3ºC / 5dk uygulamasının ilave olarak 3 gün ($p<0.05$) (toplamda 15 gün) raf ömrünü arttırdığı tesbit edilmiştir.

iii) Kısa raf ömrüne sahip yağlı balıkların raf ömrünü YSB uygulayarak arttımak (çalışılan koşullarda) mümkün olmakla birlikte, uygulanan YSB işlemini basınç seviyesine bağlı olarak duyusal özellikleri etkileyebilmektedir. Bu bağlamda endüstriyel uygulamalar öncesi önceliklerin tesbitinde yarar vardır.

C) Kültür alabalığı *(Onchorynchus mykiss)*:

i) Kültür alabalığında *(Onchorynchus mykiss)* uygulanan 7, 15 ve 25℃, 5 ve 10 dakika ile 220, 250 ve 330 MPa kombinasyonlarında renk, Trimetilamin azot (TMA-N), Tiyobarbitürik asit sayısı (TBA) ve serbest amino asit analizleri yapılmış ve kontrol grubuyla karşılaştırılmıştır.

ii) Çalışılan deneysel parametrelerin fiziksel (renk) ve kimyasal (TMA ve TBA) analizleri en uygun YHB koşullarının 220 ve 250 MPa düzeyindeki -göreceli-düşük basınçlarda elde edildiği; basıncın 220 MPa olarak seçilmesi halinde kombinasyonun 7-15-25 °C'lerde 10 dk; basıncın 250 MPa seçilmesi halinde ise sadece 7 ve 15°C'lerde 5 dk kombinasyonunun uygun olduğu sonucuna varılmıştır.

iii) YSB uygulanmış alabalık örneklerinde önemli ($p<0.05$) serbest amino asit değişimleri-kontrole göre- tesbit edilmiştir. Bu değişimler balığın aroma ve tadında değişimlere yolaçabileceği gibi, saklama sırasındaki kalite parametrelerini de etkileyebilir.

iv) 7 ve 15°C'lerde artan basınçla ve tutma zamanıyla serbest amino asit miktarındaki değişimlerin arttığı gözlenmiştir.

v) YSB uygulaması sonucu oluşan aminoasit değişimleri 25°C'de 7 ve 15°C'lerdekine göre yavaşlamaktadır.

D) İstavrit *(Trachurus trachurus)*:

i) İstavrit *(Trachurus trachurus* uygulanan 7, 15 ve 25℃, 5 ve 10 dakika ile 220, 2 50 ve 330 MPa kombinasyonlarında renk, Trimetilamin azot (TMA-N), Tiyobarbitürik asit sayısı (TBA) ve serbest amino asit analizleri yapılmış ve kontrol grubuyla karşılaştırılmıştır.

ii) Çalışılan deneysel parametrelerin fiziksel (renk) ve kimyasal (TMA ve TBA) analizleri en uygun YHB koşullarının 220 ve 250 MPa düzeyindeki -göreceli-düşük basınçlarda elde edildiği; basıncın 220 MPa olarak seçilmesi halinde kombinasyonun 15-25°C'lerde 5 dk; basıncın 250 MPa seçilmesi halinde ise sadece 7 ve 15°C'lerde 5 dk kombinasyonunun uygun olduğu sonucuna varılmıştır.

iii) YSB uygulanmış örneklerde önemli ($p<0.05$) serbest amino asit değişimleri-kontrole göre- tesbit edilmiştir. Bu değişimler balığın aroma ve tadında değişimlere yolaçabileceği gibi, saklama sırasındaki kalite parametrelerini de etkileyebilir.

6. Referanslar

ALPAS, H., J. LEE, F. BOZOGLU, G. KALETUNC "Evaluation of High Hydrostatic Pressure-sensitivity of *Staphylococcus aureus* and *Escherichia coli* O157:H7 by Differential Scanning Calorimetry", *International Journal of Food Microbiology*, 87, 229-237 (2003).

AMERINA, M. A., PANGBORN, R. V., ROESSLER, E. B.. *Principles of sensory evaluation of food*. New York, Academic Press.(1965).

ANTONACOPOULOS, N., VYNCKE, W. Determination of volatile basic nitrogen in fish, *Zeitschrift für Lebensmittel-Untersuchung und Forschung*,189, 309–316 (1989).

AOAC Official Method 971.14, Trimethylamine Nitrogen in Seafood Colorimetric Method. In: Hungerford JM Chapter Editor. *Fish and Other Marine Products.* In: Cunniff, P. Eds. Official Methods of Analysis of AOAC International, Chapter 35, p 7, (1998).

BAUMGART, J. Lebensmittel tierischer Herkunft, Feinkosterzeugnisse, gefrorene, tiefgefrorene und getrocknete Lebensmittel, Fertiggerichte, hitzekonservierte Lebensmlttel, Speiseeis, Zucker, Kakao, Zuckerwaren, Rohmasscn. In: Baumgart, Led. *Mikrobiologtsche Untersuchung von Lebensmitteln*. Hamburg: Behr's, 59. (1986).

BUZRUL, S. *High Hydrostatic Pressure (HHP) applications in food science: A study on compression heating, microbial inactivation kinetics, pulsed pressure and high pressure carbon dioxide treatments*. Doktora Tezi, University of Bordeaux 1 and Middle East Technical University. France-Turkey, (2008).

BUZRUL, S., H. ALPAS, A. LARGETEAU, G. DEMAZEAU Efficiency of pulse pressure treatment for inactivation of *Escherichia coli* and *Listeria innocua* in whole milk", *European Food Research and Technology*, 229, 127-131 (2009).

BÜYÜKCAN, M., F. BOZOGLU, H. ALPAS Preservation and Shelflife Extension of Shrimps and Clams by High Hydrostatic Pressure", *International Journal of Food Science and Technology*, 44, 1495-1502 (2009).

CAMPUS, M. High pressure processing of meat, meat products and seafood. *Food Engineering Reviews*, 2, 256-273 (2010).

CARDELLO, A.V., SCHUTZ, H.G., LESHER, L.L. Consumer perceptions of foods processed by innovative and emerging technologies: A conjoint analytic study. *Innovative food Science and emerging Technologies*, 8, 73-83 (2007).

CHEVALIER, D., LE BAIL, A., GHOUL, M. Effects of high pressure treatment (100–200 MPa) at low temperature on turbot (*Scophthalmus maximus*) muscle. *Food Research International*, 34: 425–429 (2001).

CHOULIARA, I, SAWAIDIS, LN., RIGANAKOS, K., KONTAMINAS, M.G. Shelf-life extension of vacuum-packaged sea bream (*Sparus aurata*) fillets by combined gamma-irradiation and refrigeration: microbiological, chemical and sensory changes. *Journal of the Scıence of Food and Agrıculture* 85 (5): 779-784 (2005).

CHOULIARA, I., SAWAIDIS, LN., RIGANAKOS, K., KONTAMINAS, M.G. Preservation of salted, vacuum-packaged, refrigerated sea bream (*Sparus aurata*) fillets by irradiation: microbiological, chemical and sensory attributes *Food Microbiology* 21 (3): 351-359 (2004).

COUNCIL DIRECTIVE 91/493/EEC of 22 July 1991 laying down the health conditions for the production and placmg on the market of fishery products. Off. EC L268, 15-34 (1991).

COUNCIL DIRECTIVE 86/609/EEC of 24 November 1986 on the approximation of laws, regulations and adminlstmtJve provisions of the Member States regarding the protection of animals used for expenmental and other scientific purposes. Off. J. EC L358, 1 (1986).

CRUZ-ROMERO, M., KELLY, A.L., KERRY, J.P. Influence of packaging strategy on microbiological and biochemical changes in high-pressure-treated oysters (*Crassostrea gigas*), *Journal of the Science of Food and Agriculture,* 88, 2713–2723 (2008).

EISENBRAND, G. Safety assessment of high pressure treated foods. *Mol. Nutr. Food Res*., 49, 1168-1174 (2005).

ERKAN, N., METIN, S., VARLIK, C., ÖZDEN, Ö. Der Einfluss von Kaliumsorbat auf die Qualität von Mittelmeermakrelen-Filets", *Deutsche Lebensmittel-Rundschau*, 97(11) 427-431 (2001).

ERKAN, N. Verderb von Fisch und Fischwaren- chemische und mikrobiologische Veränderungen und Gefahren, *Rundschau für Fleischhygiene und Lebensmittelüberwachung*, 55(11) 254-258 (2003a).

ERKAN, N. Tauchen von Fischfilets (*Scomber colias* und *Mugil cephalus*) in Natriumlactat und Propylgallat: Einfluss auf die Haltbarkeit und Qualität, *Archiv für Lebensmittelhygiene*, 54(3), 60-64 (2003b).

ERKAN, N., ÖZDEN, Ö., ÜÇOK ALAKAVUK, D., YILDIRIM, Ş. Y., İNUĞUR, M. Spoilage and shelf life of sardines (*Sardina pilchardus*) packed in modified atmosphere, *European Food Research and Technology*, 222(5-6), 667-673 (2006).

ERKAN, N. and ÖZDEN, Ö. Quality assessment of whole and gutted sardine (*Sardine pilchardus*) stored in ice, *International Journal of Food Science and Technology,* 43(9), 1549-1559 (2008).

ERKAN, N., SELÇUK, A., ÖZDEN, Ö. Amino acid and vitamin composition of raw and cooked horse Mackerel. *Food Analytical Method*. 3 ,269-275 (2010).

GERDES, D.L., SANTOS VALDEZ, C. Modified atmosphere packaging of commercial Pacific red snapper (*Sebastes entomelas, Sebastes flavidus* or *Sebastes godei*) *Lebensmittel-Wissenschaft und Technologie,* 24, 256-258 (1991).

GİMÉNEZ, B., RONCALÉS, P., BELTRÁN, J.A. Modified atmosphere packaging of filleted rainbow trout. *Journal of the Science of Food and Agriculture*, 82, 1154-1159 (2002).

GRAM, L. and HUSS, HH. Part II. *Microbiological ecology of different types of food*. Chapter 21. Fresh and Processed Fish and Shellfish. P.472-497. Editor. Lund, B.M., Baird-Parker, T.C., Gould, G.W. In. *The Microbiological Safety and Quality of Food*, Volume 1. Springer, ISBN: 0834213230, 9780834213234. (2000).

HE, H., ADAMS, R.M., FRAKAS, D.F., MORRİSSEY, M.T. Use of high presure processing for oyster shucking and shelf life extension. *Journal of Food Science*, 67(2):640-645 (2002).

HURTADO, J.L., MONTERO, P., BORDERIAS, J. Chilled storage of pressurized octopus (Octopus vulgaris) muscle. *Journal of Food Science*, 66(3): 400-406 (2001).

HUSS, H. H. Assurance of Seafood Quality, *FAO Fisheries Technical Paper,* 334, 46-47 (1994).

HUSS, H.H. Fresh fish quality and quality changes, FAO Fisheries Series, No. 29. Rome: FAO (1988).

LUDORFF, W., MEYER, V. *Fische und Fischerzeugnisse*, Paul Parey Verlag, Hamburg. Berlin. (1973).

MASYINOM, P., BENJAKUL, S., VISESSANGUAN, W. Shelf- life extension of refrigerated sea bass slices under modified atmosphere packaging. *Journal of the Science of Food and Agriculture* 82 873-880 (2002).

METİN, S., ERKAN, N., VARLIK, C., ARAN, N. Extension of shelf-life of chub mackerel (*Scomber japonicus* Houttuyn 1780) treated with lactic acid, *European Food Research and Technology,* 213(3), 174-177 (2001).

NORTON, T. VE SUN, DA-WEN. Recent Advances in the Use of High Pressure as an Effective Processing Technique in the Food Industry, *Food Bioprocess Technol*. 1:2–34 (2008).

OKPALO, C.O.R., PİGGOTT, J.R., SCHASCHKE, C.J. Influence of high-pressure processing (HPP) on physico-chemical properties of fresh cheese. *Innov Food Sci Emerg Technol.* 11, 61-67 (2010).

OLSEN, N.V., GRUNERTB, K. G., SONNE, A. Consumer acceptance of highpressure Processing and pulsed-electric field: a review, *Trends in Food Science and Technology* 21 464-472 (2010).

ORDÓÑEZ, J.A., LÓPEZ-GÁLVEZ, D.E., FERNÁNDEZ, M., HIERRO, E., HOZ, L.DE LA. Microbial and physicochemical modifications of hake (*Merluccius merluccius*) steaks stored under carbon dioxide enriched atmospheres. *Journal of the Science of Food and Agriculture,* 80, 1831-1840 (2000).

ÖZDEN, Ö., İNUĞUR, M., ERKAN, N., Effect of different dose gamma radiation and refrigeration on the chemical and sensory properties and microbiological status of aqua cultured sea bass (*Dicentrarchus labrax*), *Radiation Physics and Chemistry,* 76(7), 1169-1178 (2007).

RANDELL, K., HATTULA, T., AHVENAINEN, R. Effect of packaging method on the quality of rainbow trout and baltic herring fillets, *Lebensmittel Wissenschaft und Technology*, 36, 56-61 (1997).

SEQUEİRA-MUNOZ, A., CHEVALİER, D., LEBAİL, A., RAMASWAMY, H.S., SİMPSON, B.K. Physicochemical changes induced in carp (*Cyprinus carpio*) fillets by high pressure processing at low temperature. *Innov Food Sci Emerg Technol.* 7, 13–18 (2006).

SMITH, J.G.M., HARDY R.S., Mc DONALD, I., TEMOLETON, J. The storage of herring (*Cuplea harengus*) in ice, refrigerated sea water and at ambient temperature, Chemical and sensory assessment. *Journal of the Science of Food and Agriculture*, 31, 375-385 (1990).

TÜLSNER, M. Fischverarbeitung. Bd.1 – Rohstoffeigenschaften von Fisch und Grundlagen der Verarbeitungsprozesse, Hamburg Behr's Verlag, 3-86022-196-5 (1994).

VARLIK, C., ERKAN, N. and BAYGAR, T. Su Ürünleri Besin Bileşimi. Edt. Varlık, C. *Su Ürünleri İşleme Teknolojisi,* Istanbul Üniversitesi, Yayın no, 4465. ISBN: 975-404-715-4 (2004)

TÜBİTAK
PROJE ÖZET BİLGİ FORMU

Proje No: 108O668
Proje Başlığı: Yüksek Sıvı Basınç (YSB) Uygulamasının Su Ürünlerinin Kalite Parametreleri ve Raf Ömrü Üzerine Etkisi
Proje Yürütücüsü ve Araştırmacılar: Prof.Dr.Hami Alpas (Yürütücü)   **Doç.Dr. Nuray Erkan Özden (Araştırmacı)**
Projenin Yürütüldüğü Kuruluş ve Adresi: ODTÜ Gıda Mühendsiliği Bölümü-06531-ODTÜ-Ankara
Destekleyen Kuruluş(ların) Adı ve Adresi: İstanbul Ün. Su Ürünleri Fak. Avlama ve İşleme Böl., İstanbul
Projenin Başlangıç ve Bitiş Tarihleri: 01/03/2009-01/03/2011

Öz (en çok 70 kelime)

Bu projede farklı yapıdaki balıklar (dumanlanmış somon, tekir, alabalık ve istavrit) için en uygun yüksek hidrostatik basınç şartlarının önemli kalite parametrelerindeki (TMA,TBA, renk, TVB-N, mikrobiyolojik ve duyusal özellikler) değişimler ışığında belirlenmiştir. En uygun YHB koşulları sırasıyla: soğuk dumanlanmış somon için 250 MPa3ºC/5dk ve 250 MPa/25ºC/10 dk; tekir için 330 MPa/3ºC/5dk ve 250 MPa/25ºC/5dk; alabalık için 220/7-15-25'ºC/10dk ve 250MPa/7 ve 15°C/ 5 dk olarak belirlenmiştir. Bu koşullarda seçilen YSB uygulamasının soğukta depolanan taze ve işlenmiş: somonda (2ºC) ilave olarak 2 haftalık; tekirde (4ºC) düşük YSB'de ilave 2 gün (toplamda 2 hafta), yüksek YSB'de ilave 3 gün (toplamda 15 gün) raf ömrü artışı sağladığı belirlenmiştir. Alabalıkda ise 330 MPa üzeri YSB uygulamasının uygun olmadığı ve 7 ve 15°C'lerde artan basınçla ve tutma zamanıyla serbest amino asit miktarındaki değişimlerin arttığı ancak bu değişimlerin 25°C'de yavaşladığı gözlenmiştir. İstavritde ise YSB uygulanmış örneklerde önemli ($p<0.05$) serbest amino asit değişimleri-kontrole göre- tesbit edilmiştir.

Anahtar Kelimeler: Yüksek sıvı basınç (YSB), dumanlanmış somon, tekir, alabalık, istavrit, raf ömrü, kalite parametreleri

Fikri Ürün Bildirim Formu Sunuldu mu? **Evet** ☐ **Gerekli Değil** ■

Fikri Ürün Bildirim Formu'nun tesliminden sonra 3 ay içerisinde patent başvurusu yapılmalıdır.

Projeden Yapılan Yayınlar:

1. Erkan, N., Üretener, G., Alpas, H., Selcuk, A., Özden, Ö., Buzrul, S. (2011). Effect of high hydrostatic pressure (HHP) treatment on physicochemical properties of horse mackerel (Trachurus trachurus). *Food and Bioprocess Technology*, DOI: 10.1007/s11947-010-0415-4.
2. Erkan, N., Alpas, H., Üretener, G., Selcuk, A., Buzrul, S. (2010). Changes in the physicochemical properties of high pressure treated rainbow trout. *Archiv für Lebensmittelhygiene*, 61 (5):183-188.
3. Erkan, N., Üretener, G., Alpas, H. (2010). Effect of high pressure (HP) on the quality and shelf life of red mullet (*Mullus surmelutus*). *Innovative Food Science and Emerging Technologies*, 11:259-264.
4. Erkan, N., Üretener, G., Alpas, H., Selçuk, A., Özden, Ö., Buzrul, S. (2011). The effect of different high pressure conditions on the quality and shelf life of cold smoked fish. *Innovative Food Science and Emerging Technologies*, doi:10.1016/j.ifset.2010.12.004

Food Bioprocess Technol
DOI 10.1007/s11947-010-0415-4

COMMUNICATION

Effect of High Hydrostatic Pressure (HHP) Treatment on Physicochemical Properties of Horse Mackerel (*Trachurus trachurus*)

Nuray Erkan · Gonca Üretener · Hami Alpas · Arif Selçuk · Özkan Özden · Sencer Buzrul

Received: 12 April 2010 / Accepted: 16 July 2010

Abstract The basic objective of this study was to determine the effect of high hydrostatic pressure (HHP; 220, 250 and 330 MPa), holding time (5 and 10 min) and temperature (7, 15 and 25 °C) on some quality parameters of horse mackerel such as colour changes, thiobarbituric acid (TBA-i) and trimethylamine nitrogen (TMA-N), free amino acid content. HHP increased L^* values of horse mackerel. The a^* and b^* of treated horse mackerel did not change significantly after HHP applications. After, HHP, TBA-i and TMA values of all HHP-treated horse mackerel samples remained unchanged than those of untreated samples. The results obtained from this study showed that the quality of high pressure treated horse mackerel is best preserved at 250 MPa, 7–15 °C for 5 min, 220 MPa, 15–25 °C for 5 min, 250 MPa, 15 °C for 10 min and 330 MPa, 25 °C for 10 min.

Keywords Horse mackerel · High hydrostatic pressure · Colour · Quality

Abbreviations

HHP	High hydrostatic pressure
MPa	Mega-Pascal
TBA	Thiobarbituric acid
TMA-N	Trimethylamine nitrogen
min	Minute

N. Erkan (✉) · Ö. Özden
Faculty of Fisheries, Department of Seafood Processing and Quality Control, Istanbul University,
Ordu Cad. No:200 34470 Laleli,
Istanbul, Turkey
e-mail: nurerkan@istanbul.edu.tr

G. Üretener
Department of Fisheries and Seafood Processing,
Istanbul University, Institute of Science,
Bozdoğan Kemeri cad. No: 6 İşitme Engelliler Okulu Yanı
Vezneciler,
Istanbul, Turkey

H. Alpas
Food Engineering Departments,
Middle East Technical University,
06531 Ankara, Turkey

A. Selçuk
Food Institute, TÜBİTAK Marmara Research Center,
Gebze, Kocaeli, Turkey

S. Buzrul
Tütün ve Alkol Piyasası Düzenleme Kurumu (TAPDK),
06520 Ankara, Turkey

Introduction

Seafoods such as fish are highly perishable food products. During handling and storage, quality deterioration of fresh fish rapidly occurs and limits the shelf life of the product (Tülsner 1994). High pressure processing is a technology that potentially addresses many, of the most recent challenges faced by the fish industry. It can facilitate the production of food products that have the quality of fresh foods but the convenience and profitability associated with shelf-life extension (López-Caballero et al. 2000a; He et al. 2002; Lakshmanan et al. 2005; Gómez-Estace et al. 2007; Erkan et al. 2010a). High hydrostatic pressure (HHP) has already become a commercially implemented technology, spreading from its origins in Japan, followed by USA and now Europe, with worldwide take-up increasing almost exponentially since 2000 (Sun and Norton 2008; Heinz and Bukow 2010). HHP processing offers advantages over conventional processing techniques, but there are factors that may limit its applicability to some fish products (Ohshima et al. 1993; Schlüter et al. 2009). Potential

Published online: 03 August 2010

detrimental changes, in appearance, texture and chemical parameter, in HHP-treated products are also dependent on the processing conditions. Undesirable changes may therefore be minimised or avoided by the judicious selection of treatment parameters. A different response to HHP treatment has been reported to occur according to different factors in marine species and products such as species nature, chemical composition and size (Yağız et al. 2007; Yağız et al. 2009).

Horse mackerel demonstrates an exceptional nutritional value in the human diet being rich in minerals, vitamins and polyunsaturated fatty acids (Özden 2010). In Turkey, horse mackerel (*Trachurus trachurus*) is usually marketed as fresh chilled in ice or as processed, i.e. salted-smoked or canned. The objective of this preliminary study was to determine the effect of HHP on some physical (colour changes) and chemical parameters (thiobarbituric acid, trimethylamine nitrogen value amino acid content) of horse mackerel. The HHP involves the combined effect of three parameters, which are pressure, temperature and time. Studies show that in general, among those parameters, magnitude of pressure is the most significantly effective parameter on the microbiological, visual and chemical quality, followed by temperature of pressurisation and operation time. Preliminary results showed that pressures 200–330 MPa at room temperature induced inactivation of bacteria (Sun and Norton 2008). The treatment ranges were chosen according to the microbial inactivation and minimise the physicochemical modifications by HHP and considering the economical aspects of HHP processing. This work will allow the determination of a suitable pressure level between 220 and 330 to carry out pressure of horse mackerels. The conservation of positive effect of optimum pressure levels is important in different temperature (7, 15 and 25 °C) and holding time (5 and 10 min); therefore, selected three different temperatures and two different times. Thus, HHP-treated horse mackerel could be used to produce minimally processed fish products at industrial scale with high physicochemical quality.

Materials and Methods

Samples

Samples were obtained from the Istanbul fish market in winter (February). Horse mackerel (*Trachurus trachurus*) were stored in boxes with ice after catching and delivered to the laboratory in 12 h. The mean weight and length of the fish was found 40.12±4.94 g and 17.03±1.22 cm. Five kilogrammes of samples were used for the experiment. Experiments were started about 18 h after the death of the fish. The fish were gutted, filleted, washed, skinned and divided portions of equal weight (15 g). The samples were covered with flexible plastic films to avoid direct contact between the samples and pressure-transmitting fluid. Then they were pressurised at 220, 250 and 330 MPa, at 7, 15 and 25 °C for 5 and 10 min. This pressure, temperature and time combinations in HHP applications, which will be commercially economical and easily accessible, is preferred. Immediately after HHP treatment, samples were frozen to −30 °C until (2–3 day) use for physical and chemical analysis. Approximately 150-g samples (ten packaged) were used for analysis of each pressure, temperature and holding time combinations.

HHP Treatment

HHP treatments were performed in a designed and constructed laboratory-scale unit (capacity: 30 cm^3, maximum pressure: 500 MPa). Water was used as the pressure-transmitting medium. The equipment consists of a pressure chamber of cylindrical design, two end closures, a means for restraining the end closures, a pressure pump and a hydraulic unit to generate high pressure for system compression, and also a temperature control device (thermostatically controlled at 2–50 °C). The pressure vessel was made of hot galvanised carbon steel and piston was hard chrome-plated and polished to mirror finish (steel-type heat-treated special K) which was processed into the required sizes at the Electrical and Electronic Engineering Department of Middle East Technical University (Ankara, Turkey). The liquid was heated prior to pressurisation to the desired temperature by an electrical heating system surrounding the chamber. Time to reach the desired pressure and also for depressurization was approximately 5–10 s for the system.

Physical and Chemical Analyses

Horse mackerel has dark and light muscle, all of the muscles before analysis has been in a food processor.

The colour of the fish samples was determined with the help of a Konica Minolta chroma metre (model CR 400/410; Minolta, Osaka, Japan). L^* (brightness), a^* (+a, red; −a, green) and b^* (+b, yellow; −b, blue) values were measured. The colorimeter was calibrated using white references (CR-A44). The colour was measured from ten fish fillets for each group. The homogenate was placed in plastic petri dishes and the colour measurement was repeated ten times. Averages and standard deviations (SD) of L^*, a^* and b^* values were calculated as the total colour differences. The total colour difference (ΔE), as calculated below, was also used for evaluation, $\Delta E = (\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{1/2}$ where ΔL^*, Δa^* and Δb^* are the difference of the L^*, a^* and b^* values between the treated samples and control (Gerdez and

Santos Valdez 1991). The thiobarbituric acid index (TBA-i) value was determined colorimetric by the method of Erkan and Özden (2008). The TBA-i was expressed as milligrams of malondialdehyde (MDA) per kilogram of sample. The concentration of malondialdehyde was calculated from a standard curve using solutions of the MDA precursor (same molecular weight) 1,1,3,3-tetraethoxy-propane into distilled water after the addition of a quantity of TBA solution. Trimethylamine nitrogen (TMA-N) was determined by the method of AOAC (1998). Standards were prepared and measured. Results of TMA-N were expressed as milligrams per 100 g of muscle. Free amino acid content of untreated and HHP-treated samples was determined using the hydrolysis and derivatization technique described by Erkan et al. (2010b). The amino acids were determined by using a high performance liquid chromatography. In this study, it was determined that cold smoked salmon contained lysine (lys), methionine (meth), isoleucine (isoleu), leucine (leu), phenylalanine (phen), valine (val), histidin (his), serine (ser), arginine (arg), cysteine (cys), tyrosine (tyr), alanine (ala), aspartic acid (asp), glutamic acid (glut), glycine (gly) and proline (prol). Amino acids were identified by comparison of their retention time with those of an authentic standard (Pierce, Amino Acid Standard Hydrolyzate, Product No: 20078 20088 20089 1800180 NCI0180, Rockford, IL, USA) and their contents were calculated on a weight basis (mg/100 g)

Statistical Analysis

Experiments were replicated twice on different occasions with different fish samples. The mean of each sample for each group was analysed three times. Results are reported as mean values±standard deviation. Significant differences between the samples (for colour, TBA-i and TMA-N analysis) were calculated by Excel XP 2003 by one-way analyses of variance using a significance level of $p<0.05$ by Tukey's honestly significant difference test. Calculations for free amino acid made were the mean, SD, coefficients of variation in percent and F—setting the confidence level at 95% test (Sümbüloğlu and Sümbüloğlu 2002).

Results and Discussion

Changes in the colour of horse mackerel samples were shown in Table 1, respectively. At 220 MPa, 7 °C for 5 min HHP-treated samples had the lowest L^* value while at 330 MPa, 25 °C for 5 min they had the L^* value highest ($p<0.05$). The invariable L^* values were found in processed horse mackerel at 250 MPa, 7 °C for 5 min, 220–250 MPa, 15 °C for 5–10 min, 220 MPa, 25 °C for 5–10 min, 250 MPa, 25 °C for 10 min and 330 MPa, 25 °C for 10 min HHP conditions. The horse mackerel muscle pressurised at 220–250 MPa at 7 °C for 10 min, at 250–330 MPa at 25 °C for 5 min, at 330 MPa at 7–15 °C for 5 and 10 min an increase ($p<0.05$) in L^* value measured by the colour compared with the control samples. Similar results were reported for HHP-treated carp (Sequeira-Munoz et al. 2006) and also for HHP mahi mahi, rainbow trout (Yağız et al. 2007), HHP sea bream (Erkan and Üretener 2010) and HHP red mullet (Erkan et al 2010a). The mechanisms of those changes are not entirely clear. However, Carlez et al. (1995) stated that one of the reasons of cooked appearance, increase in L^* value could be denaturation of proteins when pressures of 200–300 MPa are applied for 10 min. Matser et al. (2000) found that pressure treatment at 150–200 MPa, 0 °C, 5 min increase the cooked appearance of fresh anglerfish, carp, pollack, mackerel and tuna muscle compared with an untreated sample. Montero et al. (2001) reported an increase in the melanosis of prawn pressurised at 400 MPa 7 °C, 10 min. Earlier browning and opaque muscle at 200 MPa, 7 °C, 10 min pressurised for prawn have been reported by López-Caballero et al. (2000b). Increased L^* value, decreased a^* value at 150 MPa, 1–5 °C, 60 min and at 200 MPa, 1–5 °C, 10 min have been reported by Amanatidou et al. (2000) for salmon.

The values of a^* and b^* varied between −0.06 and 3.1, and 4.9 and 8.5, respectively for HHP-treated horse mackerel. Not significantly a^* values compared with the untreated samples were found in the following condition: 220–250–330 MPa, 7 °C for 5 min, 220–330 MPa, 15 °C for 5 min, 220–250–330 MPa, 25 °C for 5 min. b^* values for HHP–treated horse mackerel samples affected not significantly ($p>0.05$) with pressure and also with pressurisation time versus the untreated for all the pressure levels tested, except for the samples pressurised at 220 MPa, 7 °C for 5 min and 220 MPa, 25 °C for 10 min. It has been reported for mackerel and cod fish that a^* values decreased after pressurisation (Ohshima et al. 1993). Similarly, redness of raw cod was lost after HHP treatment at ≥200 MPa (Angsupanich et al. 1999). Erkan et al. (2010a) reported that a^* and b^* values of fresh red mullet were not affected after treatment at 250 MPa, 3–7–15–25 °C for 5 min.

The total colour differences (ΔE) between samples of pressurised sea food are reported as appropriate indicators for changes in colour (Chevalier et al. 2001). Minimum ΔE values were found in the following HHP condition: 220 MPa, 7–15 °C for 5 min, 220 MPa, 15–25 °C for 10 min, 250 MPa, 25 °C for 10 min, 250 MPa, 7 °C for 5 min for horse mackerel. Turbot fillets were subjected to high pressures of between 100 and 200 MPa, for 15 or 30 min and greater changes were observed with pressure and time. In this study, the fewest changes were recorded for treatment at 140 MPa, 4 °C, 15 min (Chevalier et al. 2001). Similar results have been published for hake (*Merluccius capensis*) muscle, which began to lose its raw

Table 1 Colour analysis results of unpressurised and pressurised horse mackerel

Temperature/time		7°C/5min	7°C/10min	15°C/5min	15°C/10min	25°C/5min	25°C/10min
L^*	Untreated	54.05 Aa	54.05 Aa	54.05 Aa	54.05 Aa	54.05 Aa	54.05 Aa
		±1.67[a]	±1.67	±1.67	±1.67	±1.67	±1.67
	220 MPa	49.97 Ba	59.22 Bb	52.29 Aa	54.06 Aa	51.99 Aa	55.42 Aa
		±2.14	±1.36	±3.83	±0.93	±4.20	±2.63
	250 MPa	54.75 Aa	59.66 Ba	57.72 Aa	53.42 Aa	63.16 Bb	55.01 Aa
		±3.00	±1.95	±2.49	±1.59	±3.93	±2.65
	330 MPa	62.70 Ca	59.50 Ba	65.74 Ba	58.19 Bb	68.91 Bb	59.34 Ab
		±5.31	±1.77	±3.04	±0.72	±3.27	±1.40
a^*	Untreated	2.75 Aa	2.75 Aa	2.75 Aa	2.75 Aa	2.75 Aa	2.75 Aa
		±0.58	±0.58	±0.58	±0.58	±0.58	±0.58
	220 MPa	2.88 Aa	−0.06 Bb	2.51 Aa	0.07 Bb	1.90 Aa	1.04 Bb
		±0.75	±0.83	±0.64	±0.68	±1.13	±0.45
	250 MPa	1.21 Aa	0.06 Bb	0.62 Ba	1.00 Ba	1.36 Aa	0.50 Ba
		±1.94	±0.47	±1.48	±0.28	±1.51	±1.46
	330 MPa	3.07 Aa	0.44 Bb	2.81 Aa	0.11 Bb	2.87 Aa	−0.19 Bb
		±0.89	±0.68	±0.90	±0.42	±1.69	±0.33
b^*	Untreated	8.89 Aa	8.89 Aa	8.89 Aa	8.89 Aa	8.89 Aa	8.89 Aa
		±0.52	±0.52	±0.52	±0.52	±0.52	±0.52
	220 MPa	4.89 Ba	7.15 Aa	5.73 Aa	6.84 Aa	5.87 Aa	5.56 Ba
		±1.71	±2.43	±2.40	±0.57	±2.00	±0.60
	250 MPa	5.45 Aa	8.50 Aa	5.12 Aa	5.99 Aa	7.40 Aa	5.84 Aa
		±3.40	±0.44	±3.03	±1.06	±2.69	±2.80
	330 MPa	7.88 Aa	7.76 Aa	8.14 Aa	8.30 Aa	6.53 Aa	5.76 Aa
		±1.44	±1.23	±0.64	±1.95	±1.15	±1.31
ΔE	Untreated	–	–	–	–	–	–
	220 MPa	4.02	8.66	4.27	4.49	7.34	5.77
		±1.09	±1.28	±1.31	±1.12	±3.31	±1.42
	250 MPa	6.84	8.59	9.42	6.33	15.31	5.87
		±4.78	±1.96	±2.10	±0.44	±4.69	±2.57
	330 MPa	15.58	8.48	18.45	7.43	20.82	9.04
		±9.31	±1.34	±6.29	±0.56	±6.09	±0.84

Different letters (A, B, C) in the same column indicate significant differences ($p<0.05$), different letters (a, b, c) in the same line indicate significant differences ($p<0.05$)

[a] SD ($n=3$)

appearance on pressurisation of the muscle at 200 MPa (three 5-min pulses) at 7 °C (Hurtado et al. 2000).

The changes in lipid oxidation parameters are directly and indirectly responsible for the quality deterioration of fish. The TBA-i is a measure of malonaldehyde content one of the degradation products of lipid hydroperoxides, formed during the oxidation process of polyunsaturated fatty acids (Gomes et al. 2003). Table 2 show the changes in TBA-i of pressurised horse mackerel, respectively. Differences in TBA-i between untreated and HPP treated (except 220 MPa, 15 °C for 10 min) horse mackerel samples were found to be insignificant ($p>0.05$). In the literature, the TBA-i values of HHP-treated fish and fish products with increasing pressure and pressure-holding times have been reported to show progressive changes (Sequeira-Munoz et al. 2006; Yağız et al. 2007). Angsupanich and Ledward (1998) reported that pressure below 400 MPa had a slight effect on lipid oxidation in cod muscle treated for 20 min at ambient temperature. However, they did not notice a significant change of the TBA number at 200 MPa. Horse mackerel not seemed to be more sensitive to applied pressure in terms of lipid oxidation. TBA-i value in HHP applications are affected pressure, time and temperature. Furthermore, lipid oxidation plays a key role in the content of unsaturated fats in fish species, iron compounds and myoglobin, haemoglobin and ferritin content in meat and fish

Table 2 TBA-i analysis results of unpressurised and pressurised horse mackerel

Temperature/time		7°C/5min	7°C/10min	15°C/5min	15°C/10min	25°C/5min	25°C/10min
TBA-i (mgMDA/kg)	Untreated	2.98 Aa ±0.38[a]	2.98 Aa ±0.38	2.98 Aa ±0.38	2.98 Aa ±0.38	2.98 Aa ±0.38	2.98 Aa ±0.38
	220 MPa	4.01 Aa ±0.65	3.16 Aa ±1.38	2.69 Aa ±0.35	4.00 Ba ±0.07	3.16 Aa ±0.76	2.70 Aa ±0.25
	250 MPa	4.50 Aa ±1.24	3.58 Aa ±0.01	2.77 Aa ±0.71	2.96 Aa ±0.01	2.85 Aa ±1.04	2.88 Aa ±0.22
	330 MPa	3.48 Aa ±0.58	3.16 Aa ±0.15	2.79 Aa ±1.30	2.31 Ca ±0.18	2.82 Aa ±0.99	2.40 Aa ±0.16

Different letters (A, B, C) in the same column indicate significant differences ($p<0.05$), different letters (a, b, c) in the same line indicate significant differences ($p<0.05$)

[a] SD ($n=3$)

(Chevalier et al. 2001). Amanatidou et al. (2000) reported that TBA-i values of fresh Atlantic salmon were not affected after HHP treatment up to 200 MPa. Chevalier et al. (2001) favourable to find changes in TBA-i levels in raw turbot muscles treated at 100–140 MPa/4 °C/15–30 min. Sequeira-Munoz et al. (2006) reported that 100-MPa pressure, 4 °C temperature, 15-min time had little effect on lipid oxidation of carp fillets while 140–180 and 400 MPa, 4 °C for 15 and 30 min had significant effect on lipid oxidation. Yağız et al. (2007) reported stable TBA-i value compared to control samples in rainbow trout dark muscle treated for 150 and 300 MPa, 15 min at room temperature. TBA-i values did not change in the raw red mullet treated 220 MPa, 3 °C for 5–10 min, 250 MPa, 7–15–25 °C for 5 min and 330 MPa, 7–15 °C for 5–10 min (Erkan et al. 2010a) and in the raw sea bream treated 220–250 MPa, 15–25 °C for 10 min control (Erkan and Üretener 2010).

TMA-N content is often used as a biochemical index to assess keeping quality of fish. In marine fish, TMA is formed from trimethylamine oxide which is a part of the non-protein nitrogen fraction of the fish flesh. TMA production is the result of bacterial enzyme activity and is the main compound responsible for an unpleasant “fishy” odour (Pons-Sánchez-Cascado et al. 2006). In this study, we tested all the HHP reconditions and it was found suitable for stability of TMA-N. On the other hand, there has been little data available documenting the TMA-N content of pressurised fish in literature. TMA-N content of pressurised horse mackerel is shown in Table 3. The TMA-N content of samples was not affected from HHP application. The TMA-N content of some of HHP-treated horse mackerel samples (at 330 MPa, 7 °C for 10 min; 220–250–330 MPa, 25 °C for 10 min) were found to be significantly ($p<0.05$) lower than the untreated horse mackerel samples. The changes were attributed to the inhibition of proteolytic activity (Hernández-Andrés et al. 2005). The effect of HHP treatment on colour, TBA and TMA parameters of red mullet was studied by Erkan et al. (2010a). These studies indicated unchanged TMA-N content for HHP treated at 220 MPa, 15 °C for 10 min, 220 MPa, 25 °C for 5 min, 250 MPa, 7–25 °C for 10 min, 330 MPa,

Table 3 TMA-N analysis results of unpressurised and pressurised horse mackerel

Temperature/time		7°C/5min	7°C/10min	15°C/5min	15°C/10min	25°C/5min	25°C/10min
TMA-N (mg/100 g)	Untreated	2.58 Aa ±0.59[a]	2.58 Aa ±0.59	2.58 Aa ±0.59	2.58 Aa ±0.59	2.58 Aa ±0.59	2.58 Aa ±0.59
	220 MPa	2.45 Aa ±0.35	2.37 Aa ±0.17	1.99 Aa ±0.56	2.11 Aa ±0.22	2.08 Aa ±0.42	1.21 Bb ±0.39
	250 MPa	1.98 Aa ±0.28	2.13 Aa ±0.19	2.78 Aa ±1.27	1.59 Aa ±0.38	2.16 Ab ±0.53	1.49 Ba ±0.25
	330 MPa	1.90 Aa ±1.23	1.53 Bb ±0.07	2.26 Aa ±0.65	2.33 Aa ±0.23	2.89 Aa ±0.18	1.37 Bb ±0.35

Different letters (A, B, C) in the same column indicate significant differences ($p<0.05$), different letters (a, b, c) in the same line indicate significant differences ($p<0.05$)

[a] SD ($n=3$)

Table 4 Free amino acid analysis results of unpressurised and pressurised horse mackerel

Amino acids (mg/ 100 g)	*C*	220 MPa, 7 °C, 5 min	220 MPa, 7 °C, 10 min	250 MPa, 7 °C, 5 min	250 MPa, 7 °C, 10 min	330 MPa, 7 °C, 5 min	330 MPa, 7 °C, 10 min	220 MPa, 15 °C, 5 min	220 MPa, 15 °C, 10 min	250 MPa, 15 °C, 5 min	250 MPa, 15 °C, 10 min	330 MPa, 15 °C, 5 min	330 MPa, 15 °C, 10 min	220 MPa, 25 °C, 5 min	220 MPa, 25 °C, 10 min	250 MPa, 25 °C, 5 min	250 MPa, 25 °C, 10 min	330 MPa, 25 °C, 5 min	330 MPa, 25 °C, 10 min
Lys	1,714	*1,786*	1,950	*1,817*	1,543	2,060	*1,782*	*1,720*	1,828	2,026	1,897	1,866	1,826	*1,755*	*1,867*	1,549	*1,723*	1,832	1,780
	±0.60	*±20.23*	±6.52	*±15.71*	±4.66	±13.76	*±12.37*	*±2.85*	±10.12	±26.74	±19.38	±1.17	±11.42	*±20.40*	±4.83	±2.18	*±29.39*	±1.98	±0.20
Meth	549	603	613	*548*	384	741	*555*	*557*	537	589	605	625	634	*568*	773	673	640	650	423
	±0.43	±0.73	±0.70	*±2.16*	±3.15	±8.63	*±2.47*	*±1.58*	±0.53	±1.30	±3.99	±0.38	±3.56	*±1.94*	±2.94	±0.83	±0.90	±3.01	±0.67
Thre	794	*799*	914	837	*773*	932	826	782	874	879	*814*	*809*	827	753	916	757	*782*	876	*834*
	±0.63	*±3.34*	±2.22	±4.12	*±2.44*	±3.50	±2.77	±1.64	±2.85	±2.21	*±44.00*	*±2.54*	±1.46	±0.89	±7.30	±3.42	*±7.05*	±0.59	*±5.69*
Isoleu	902	*905*	1,043	*936*	816	1,070	*928*	*903*	*912*	1,017	980	961	*946*	*888*	1,073	*948*	*899*	1,040	*950*
	±0.20	*4.06*	±2.69	*±4.94*	±6.12	±2.82	*±8.75*	*±10.02*	*±9.09*	±10.69	±5.61	±2.55	*±9.10*	*±4.46*	±7.72	*±13.69*	*±4.27*	±3.88	*±6.50*
Leu	1,338	*1,363*	1,553	1,430	*1,172*	1,605	*1,373*	*1,360*	1,429	1,572	1,466	1,465	*1,419*	*1,336*	1,622	*1,419*	*1,370*	1,514	1,441
	±0.18	*±6.15*	±1.44	±16.97	*±6.71*	±2.80	*±14.97*	*±14.98*	±1.37	±7.87	±3.89	±13.72	*±12.26*	*±8.40*	±4.35	*±25.61*	*±25.00*	±4.02	±11.22
Phen	759	828	890	831	855	920	793	*786*	807	865	826	*792*	833	*791*	879	*765*	803	801	819
	±0.21	±4.40	±7.01	±4.20	±3.32	±4.56	±0.87	*±4.05*	±2.28	±2.68	±0.65	*±10.75*	±3.70	*±11.82*	±0.41	*±0.98*	±3.84	±0.72	±5.53
Val	953	*939*	1,115	1,007	1,013	1,130	*978*	985	*1,010*	1,094	*997*	*997*	*984*	*916*	1,195	1,030	*946*	1,162	1,010
	±0.25	*±3.84*	±9.79	±5.47	±2.10	±13.65	*±5.99*	±1.96	*±28.36*	±1.28	*±13.28*	*±12.70*	*±7.57*	*±5.33*	±0.24	±2.03	*±3.65*	±10.86	±2.79
His	649	581	699	613	563	*660*	602	606	618	614	729	*648*	*618*	602	719	*654*	500	723	592
	±0.44	±0.44	±3.05	±2.09	±4.84	*±1.62*	±1.41	±3.73	±1.31	±2.39	±0.70	*±4.16*	*±3.14*	±1.76	±3.22	*±2.44*	±0.53	±3.45	±5.78
Ser	761	731	8,322	813	819	868	885	789	1,017	836	*770*	*764*	870	701	965	*739*	*741*	881	785
	±0.15	±0.49	±2.25	±4.91	±2.90	±2.01	±4.92	±1.71	±3.74	±2.32	*±1.95*	*±4.85*	±2.57	±6.28	±3.35	*±8.27*	*±3.71*	±5.03	±1.11
Arg	1,522	1,411	1,773	1,579	1,701	1,631	*1,523*	*1,630*	1,939	1,631	1,639	1,588	*1,518*	1,391	1,742	1,409	*1,478*	1,538	1,775
	±0.93	±2.49	±1.07	±7.04	±8.03	±2.78	*±7.41*	*±0.52*	±8.93	±2.96	±3.28	±0.94	*±7.92*	±4.10	±14.12	±3.29	*±11.82*	±0.01	±2.25
Cys	176	161	113	118	*155*	*160*	104	126	110	100	142	107	123	*150*	*180*	*160*	128	*174*	136
	±3.91	±2.85	±1.32	±1.99	*±0.12*	*±0.35*	±1.02	±0.46	±1.79	±0.12	±1.31	±2.22	±1.73	*±0.01*	*±0.20*	*±2.44*	±0.24	*±0.66*	±0.01
Tyr	662	*685*	754	717	706	799	710	*671*	*702*	720	766	*668*	*697*	*670*	876	765	*674*	818	*669*
	±0.94	*±3.77*	±2.14	±4.73	±3.75	±0.04	±2.29	*±3.10*	*±10.67*	±0.51	±6.15	*±2.92*	*±5.47*	*±3.69*	±6.24	±3.96	*±7.00*	±8.29	*±3.42*
Ala	952	1,053	1,386	1,132	1,151	1,281	1,088	1,280	1,404	1,188	1,044	1,081	1,036	*944*	1,093	764	1,057	1,002	1,066
	±0.66	±11.07	±5.52	±2.30	±17.05	±15.53	±2.00	±11.06	±14.95	±3.01	±8.07	±2.91	±1.15	*±3.05*	±0.61	±7.19	±2.92	±4.81	±1.18
Asp	1,761	1,853	2,172	1,898	1,673	2,214	1,914	1,959	2,027	2,129	1,913	1,966	*1,835*	*1,749*	*1,812*	1,477	*1,799*	*1,791*	1,902
	±0.11	±7.25	±11.17	±1.22	±9.68	±8.17	±6.19	±4.71	±12.25	±2.52	±4.33	±13.83	*±10.50*	*±4.51*	*±7.14*	±0.76	*±9.97*	*±9.14*	±1.09
Glut	2,597	*2,711*	3,202	*2,871*	*2,521*	3,267	2,764	2,855	2,952	3,065	*2,733*	2,923	2,744	*2,645*	2,719	2,212	*2,693*	*2,669*	2,779
	±0.47	*±16.53*	±23.67	*±37.94*	*±13.27*	±18.97	±0.73	±6.31	±23.84	±23.44	*±22.96*	±3.59	±0.63	*±53.92*	±5.00	±23.66	*±12.79*	*±9.69*	±5.73
Gly	1,001	841	1,417	*999*	1,880	1,049	911	1,472	1,786	932	747	911	1,101	795	1,630	1,055	*1,005*	1,104	1,112
	±0.33	±6.34	±8.25	*±0.73*	±9.24	±1.67	±2.48	±10.54	±13.27	±2.50	±2.19	±0.00	±3.44	±2.06	±4.96	±1.21	*±9.14*	±2.94	±4.81
Prol	591	575	891	653	931	718	*577*	885	976	*593*	*538*	*576*	*644*	520	757	529	*580*	*605*	680
	±3.20	±4.86	±1.36	±0.13	±4.64	±2.71	*±6.60*	±0.03	±1.55	*±4.89*	*±3.61*	*±5.99*	*±28.80*	±4.41	±2.37	±4.20	*±2.79*	*±7.09*	±5.72

Insignificant data compared to control are shown in italics

3 °C for 5 min. Similarly, Erkan and Üretener (2010) determined in HHP-treated sea bream (at 220–250–330 MPa, 7 and 15 °C for 5 min; at 330 MPa, 3 and 7 °C for 10 min) insignificant TMA-N level than untreated samples.

Generally, fish and shellfish meat is considered to be highly nutritious, owing to its content of essential amino acids and proteins. In addition to their dietary importance, proteins affect food texture, as also do small peptides, and free amino acids contribute to food flavour (Belitz and Grosch 1999). The concentration of these constituents in sea foods have been of interest because of their important influence on the sensory properties. Therefore, food analysts and seafood technologists have been interested in changes in the nature and amounts of the various chemical components occurring after processing, during storage and ripening in the edible parts of sea foods because of their impact on the market quality of the food product. Although the amino acid composition of a variety of sea foods has been known for many years, relatively little information has been collected on the amino acid composition of HHP-treated fish and shellfish (Erkan et al. 2010c). HHP-treated horse mackerel samples showed significantly increased or decreased free amino acid content ($p<0.05$) relative to untreated horse mackerel fillets (Table 4). The cause of decline and rise is protein denaturation. After, HHP denaturation of food proteins have been reported (Sendra et al. 2000). Reflection of the changes in amino acids is more pronounced in raw sea food. Cooked images of HHP-treated raw fish are associated with changes of free amino acid content after HHP treatment (Erkan et al. 2010c). This situation is similar to us in our work.

Conclusion

In conclusion, horse mackerel were subjected to HHP treatments at 220, 250 and 330 MPa; 7, 15 and 25 °C for 5 and 10 min. In the selection of the best HHP conditions close to control values or lower than the control colour, TBA-i and TMA-N values were based and are assessed together. Colour, TMA-N and TBA-i results indicated that HHP-treated horse mackerel used in this trial had a best condition HHP of at 250 MPa, 7–15 °C for 5 min, 220 MPa, 15–25 °C for 5 min, 250 MPa, 15 °C for 10 min and 330 MPa, 25 °C for 10 min, respectively. These results may lead to practical applications of HHP treatment in the seafood industry to produce microbiologically safe, minimally processed products with high quality.

Acknowledgments This work was supported by the TUBİTAK-TOVAG projects (No: 108O668) and the Research Found of Istanbul University (Project Number BYP-2861).

References

Angsupanich, K., & Ledward, D. A. (1998). High pressure treatment effects on cod (*Gadus morhua*) muscle. *Food Chemistry, 63*, 39–50.

Angsupanich, K., Edde, M., & Ledward, D. A. (1999). Effects of high pressure on the myofibrillar proteins of cod and turkey muscle. *Journal of Agricultural and Food Chemistry, 47*, 92–99.

Amanatidou, A., Schülüter, O., Lemkau, K., Gorris, L. G. M., Smid, E. J., & Knorr, D. (2000). Effect of combined application of high pressure treatment and modified atmospheres on the shelf life of fresh Atlantic salmon. *Innovative Food Science & Emerging Technologies, 1*, 87–98.

AOAC (1998). AOAC Official Method 971.14, Trimethylamine Nitrogen in Seafood Colorimetric Method. In: Hungerford JM *(Chapter Ed.), Fish and Other Marine Products.* In: Cunniff, P. (Ed.), Official Methods of Analysis of AOAC International, Chapter 35, p 7.

Belitz, H. D., & Grosch, W. (1999). *Food Chemistry* (p. xliii+992). Berlin: Springer Verlag. ISBN: 3-540-64692-2.

Carlez, A., Veciananogues, T., & Cheftel, J. C. (1995). Changes in color and myoglobin of minced beef meat due to high-pressure processing. *Food Science and Technology-Lebensmittel-Wissenschaft and Technologie, 28*(5), 528–538.

Chevalier, D., Le Bail, A., & Ghoul, M. (2001). Effects of high pressure treatment (100–200 MPa) at low temperature on turbot (*Scophthalmus maximus*) muscle. *Food Research International, 34*, 425–429.

Erkan, N., & Özden, Ö. (2008). Quality assessment of whole and gutted sardine (*Sardine pilchardus*) stored in ice. *International Journal of Food Science & Technology, 43*(9), 1549–1559.

Erkan, N., & Üretener, G. (2010). The effect of high hydrostatic pressure on the microbiological, chemical and sensory quality of fresh gilthead sea bream (*Sparus aurata*). *European Food Research and Technology, 230*(4), 533–542.

Erkan, N., Üretener, G., & Alpas, H. (2010). Effect of high pressure (HP) on the quality and shelf life of red mullet *(Mullus surmelutus*). *Innovative Food Science & Emerging Technologies, 11*(2), 259–264.

Erkan, N., Selçuk, A., & Özden, Ö. (2010). Amino acid and vitamin composition of raw and cooked horse mackerel. *Food Analytical Methods, 3*(3), 269–275.

Erkan, N., Alpas, H., Üretener, G., Selçuk, A., Buzrul, S. (2010c). Changes in the physicochemical properties of high pressure treated rainbow trout. *Archiv für Lebensmittelhygiene*. (in press).

Gerdez, D. L., & Santos Valdez, C. (1991). Modified atmosphere packaging of commercial Pacific red snapper (*Sebastes entomelas, Sebastes flavidus* or *Sebastes godei*). *Lebensmittel Wissenschaft und Technology, 24*, 256–258.

Gomes, H. A., Silva, E. N., Nascimento, M. R. L., & Fukuma, H. T. (2003). Evaluation of the 2-thiobarbituric acid method for the measurement of lipid oxidation in mechanically deboned gamma irradiated chicken meat. *Food Chemistry, 80*(3), 433–437.

Gómez-Estace, J., Gómez-Guillén, P., & Montero, P. (2007). High pressure effects on the quality and preservation of cold-smoked dolphinfish (*Coryphaena hippurus*) fillets. *Food Chemistry, 102*, 1250–1259.

He, H., Adams, R. M., Farkas, D. F., & Morrissey, M. T. (2002). Use of high-pressure processing for oyster shucking and shelf-life extension. *Journal of Food Science, 67*(2), 640–645.

Heinz, V., & Bukow, R. (2010). Food preservation by high pressure. *Journal für Verbraucherschutz und Lebensmittelsicherheit, 5*, 73–81.

Hernández-Andrés, A., Gómez-Guillén, C., Montero, P., & Pérez-Mateos, M. (2005). Partial characterization of protease activity in squid (*Todaropsis eblanae*) mantle: Modification by high-pressure treatment. *Journal of Food Science, 70*(4), C239–C245.

Hurtado, J. L., Montero, P., & Borderías, A. J. (2000). Extension of shelf life of chilled hake (*Merluccius capensis*) by high pressure. *Food Science and Technology International, 6*, 243–249.

Lakshmanan, R., Miskin, D., & Piggot, J. R. (2005). Quality of vacuum packed cold-smoked salmon during refrigerated storage as affected by high-pressure processing. *Journal of the Science of Food and Agriculture, 85*, 655–661.

López-Caballero, M. E., Pérez-Mateos, M., Montero, P., & Borderías, A. J. (2000). Oyster preservation by high-pressure treatment. *Journal of Food Protection, 63*, 196–201.

López-Caballero, M. E., Pérez-Mateos, M., Borderías, A. J., & Montero, P. (2000). Extension of shelf life of prawns (*Penaeus japonicus*) by vacuum packaging and high-pressure treatment. *Journal of Food Protection, 63*, 1381–1388.

Matser, A. M., Stegeman, D., Kals, J., & Bartels, P. V. (2000). Effects of high pressure on colour and texture of fish. *High Pressure Research, 19*, 109–115.

Montero, P., López-Caballero, M. E., & Pérez-Mateos, M. (2001). The effect of inhibitors and high pressure treatment to prevent melanosis and microbial growth on chilled prawns (*Penaeus japonicus*). *Journal of Food Science, 66*, 1201–1206.

Ohshima, T., Ushio, H., & Koizumi, C. (1993). High-pressure processing of fish and fish products. *Trends in Food Science and Technology, 4*, 370–375.

Özden, Ö. (2010). Micro, macro mineral and proximate composition of Atlantic bonito and horse mackerel: a monthly differentiation. *International Journal of Food Science, 45*(3), 578–586.

Pons-Sánchez-Cascado, S., Veciana-Nogués, M. T., Mariné-Font, S. B. A., & Vidal-Carou, M. C. (2006). Use of volatile and non-volatile amines to evaluate the freshness of anchovies stored in ice. *Journal of the Science of Food and Agriculture, 86*, 699–705.

Schlüter, O., Foerster, J., Geyer, M., Knorr, O., & Herppich, W. B. (2009). Characterization of high-hydrostatic-pressure effects on fresh produce using chlorophyll fluorescence image analysis. *Food and Bioprocess Technology, 2*, 291–299.

Sendra, E., Saldo, J., Capellas, M., & Guamis, B. (2000). Decrease of free amino acids in high-pressure treated cheese. *High Pressure Research, 19*, 33–36.

Sequeira-Munoz, A., Chevalier, D., LeBail, A., Ramaswamy, H. S., & Simpson, B. K. (2006). Physicochemical changes induced in carp (*Cyprinus carpio*) fillets by high pressure processing at low temperature. *Innovative Food Science & Emerging Technologies, 7*, 13–18.

Sun, D. W., & Norton, T. (2008). Recent advances in the use of high pressure as an effective processing technique in the food industry. *Food and Bioprocess Technology, 1*, 2–34.

Sümbüloğlu, K. and Sümbüloğlu, V. (2002). *Biyoistatistik*. 10. Baskı, p.275, Hatipoğlu Basım ve Yayım San. Tic. Ltd. Sti. ISBN: 975-7527-12-2. Ankara.

Tülsner, M. (1994). *Fischverarbeitung. Bd.1 – Rohstoffeigenschaften von Fisch und Grundlagen der Verarbeitungsprozesse*. Hamburg: Behr's Verlag. ISBN: 3-86022-196-5.

Yağız, Y., Kristinsson, H. G., Balaban, M. O., & Marshall, M. R. (2007). Effect of high pressure treatment on the quality of rainbow trout (*Oncorhynchus mykiss*) and mahi mahi (*Coryphaena hippurus*). *Journal of Food Science, 72*(9), C509–C515.

Yağız, Y., Kristinsson, H. G., Balaban, M. O., Bruce, A. W., Ralat, M., & Marshall, M. R. (2009). Effect of high pressure processing and cooking treatment on the quality of Atlantic salmon. *Food Chemistry, 116*, 828–835.

Arch Lebensmittelhyg 61,
183–188 (2010)
DOI 10.2376/0003-925X-61-183

ISSN 0003-925X

Korrespondenzadresse:
nurerkan@istanbul.edu.tr

[1]Istanbul University, Faculty of Fisheries, Department of the Seafood Processing and Quality Control, 34470, Istanbul, Turkey; [2]Food Engineering Departments, Middle East Technical University, 06531, Ankara, Turkey; [3]Istanbul University, Institute of Science, Department of Fisheries and Seafood Processing, Bozdoğan Kemeri cad. No: 6 İşitme Engelliler Okulu Yanı Vezneciler/Istanbul, Turkey; [4]Food Institute, TÜBİTAK Marmara Research Center, Gebze/Kocaeli, Turkey; [5]Tütün ve Alkol Piyasası Düzenleme Kurumu (TAPDK), 06520, Ankara, Turkey

Changes in the physicochemical properties of high pressure treated rainbow trout

Hochdruckbehandlung von Regenbogenforellen

Nuray Erkan[1], Hami Alpas[2], Gonca Üretener[3], Arif Selçuk[4], Sencer Buzrul[5]

Summary

Changes in the physicochemical quality of rainbow trout's High pressure (HP)-treated at 220, 250 and 330 MPa, 7, 15 and 25 ºC for 5 and 10 min were investigated. HP-treated rainbow trout's showed significantly increased L* value relative to untreated rainbow trout's. Little changes in colour (a* value) were observed, compared to untreated rainbow trout's, which did not showed b* values. From tests of chemical properties, HP-treated rainbow trout's did not showed or showed significantly decreased thiobarbituric acid (TBA) and trimethylamine nitrogen (TMA-N) with increasing treatment pressure compared to controls. HP-treated rainbow trout samples showed significantly increased or decreased free amino acids ($P < 0.05$) relative to untreated trout samples. The results obtained from this study showed that the quality of HP-treated rainbow trout is best preserved at 220 MPa, 7–15–25 ºC for 5–10 min and 250 MPa, 7–15 ºC for 5 min.

Keywords: rainbow trout, high pressure, colour, lipid oxidation, free amino acid

Zusammenfassung

Untersucht wurden physikalisch-chemische Qualitätsveränderungen von Regenbogenforellen, die mit 220, 250 und 330 MPa, bei 7, 15 und 25 ºC für 5 und 10 min behandelt wurden. Die Hochdruck (HP)-behandelten Regenbogenforellenen zeigten signifikant erhöhte L * Werte im Vergleich zu unbehandelten Regenbogenforellen. Geringgradige Änderungen der Farbe (a * Wert) wurden, im Vergleich zu den unbehandelten Regenbogenforellen, beobachtet, jedoch nicht bei den b * Werten. Bei der Untersuchung der chemischen Eigenschaften, zeigten die HP-behandelten Regenbogenforellen keine oder keine signifikante Zunahme von Thiobarbitursäure (TBA) und Trimethylamin-Stickstoff (TMA-N) mit wachsendem Druck bei der Behandlung im Vergleich zur Kontrollgruppe. Die HP-behandelten Proben zeigten eine erhebliche Zunahme bzw. Abnahme der freien Aminosäuren ($P < 0{,}05$) im Vergleich zu den unbehandelten Proben. Die Ergebnisse dieser Studie haben gezeigt, dass die Qualität der HP-behandelten Regenbogenforellen am besten bei 220 MPa, 7–15–25 ºC für 5–10 min und bei 250 MPa, 7–15 ºC für 5 min erhalten bleibt.

Schlüsselwörter: Regenbogenforellen, Hochdruckbehandlung, Farbe, Lipidoxidation, freie Aminosäuren

Introduction

Several species of freshwater fish including carp, rainbow trout are being farmed in Turkey and in other Europe countries over the last decade in order to meet the increasing demand for fresh rather than frozen fish. Of the freshwater fish species, rainbow trout *(Onchorynchus mykiss)* is being farmed mainly in the river waters of North-middle Anatolia and is sold as either whole fresh fish and in fillet in retail markets, supermarkets. Additionally, trout fillets in the form of smoked and vacuum packaged products are being exported to various European countries. Sea foods such as fish are highly perishable food products. During handling and storage, quality deterioration of fresh fish rapidly occurs and limits the shelf life of the product. Freshwater fish are extremely perishable food commodities (Tülsner, 1994).

High pressure (HP) treatment is an alternative food preservation technology to thermal treatment or chemical preservations. There are also HP- treated fish products introduced into the market. Positive effect of HP treatment on shelf life of octopus, oyster, shrimp, mussel and raw fish have been reported (Hurdato et al., 2001; He et al., 2002; Cruz-Romero et al., 2008a; Büyükcan et al., 2009; Erkan and Üretener, 2010).

But, the effects of pressure on the structural, textural, and colour changes of sea foods are more variable compared to many other foods (Yağız et al., 2007). Visual assessment of appearance (especially colour) is one of the most important factors affecting the consumer acceptability of seafood (Cruz- Romero et al., 2008b). Some modifications in colour have been reported for fish after HP treatment (Amanatidou et al., 2000; Chevalier et al., 2001; Yağız et al., 2007).

Lipid oxidation is a major quality problem in fish (Erkan and Özden, 2008). The primary product of lipid oxidation is the fatty acid hydroperoxide, measured as peroxide value (PV). Peroxides are not stable compounds and they break down to aldehydes, ketones, and alcohols, which are the volatile products causing off flavour in products (Fernandez et al, 1997). The Thiobarbituric acid (TBA) values measure secondary products of lipid oxidation. Ohshima et al. (1993) reported an increase in both the peroxide value (PV) and TBA numbers (both measurements of lipid oxidation) of HP- treated fish muscles.

Trimethylamine nitrogen (TMA-N), have been used as freshness indicators in sea foods (Tülsner, 1994). Limited information is available on HP of seafood, and more specifically, its effect on TMA-N profile (Erkan and Üretener, 2010).

Denaturation of protein is one of the major biochemical events during HP treatment. During treatment its degradation products, amino acids and peptides, have a considerable effect on the sensory characteristics of fish. However, only limited information is available in the literature on free amino acid changes of HP-treated sea foods (Cruz-Romero et al., 2008c).

The objective of this study was to investigate the effect of different HP conditions (pressure; 220, 250 and 330 MPa, holding time; 5 and 10 min and temperature; 7, 15 and 25 °C) on some physicochemical characteristics (colour changes, TBA, TMA-N value and amino acid content) of rainbow trout.

Materials and methods

Samples

Aqua cultured fresh rainbow trout were cultivated in net cages in a Turkish fish farm. A total of three kg rainbow trout were killed by immersing in ice-cold water (hypothermia) (Council Directive 86/609/EEC), packed with melted ice (2:1, fish: ice) in polystyrene boxes (Council Directive 91/493/EEC) provided with holes for drainage and were transported to the laboratory. The fish were gutted, filleted and washed. Three kilograms of samples were used for the experiment. Experiments were started about 18 hours after the death of the fish. The fish were filleted, skinned and divided portions of equal weight (15 g). The samples were covered with flexible plastic films to avoid direct contact between the samples and pressure transmitting fluid. Then they were pressurized at 220, 250 and 330 MPa at 7, 15 and 25 °C for 5 and 10 min. Immediately after HP treatment, samples were frozen to –30 °C until use for physical and chemical analysis.

HP treatment

HP treatments were performed in a designed and constructed laboratory-scale unit (capacity: 30 cm^3, maximum pressure: 500 MPa). Water was used as the pressure-transmitting medium. The equipment consists of a pressure chamber of cylindrical design, two end closures, a means for restraining the end closures, a pressure pump and a hydraulic unit to generate high pressure for system compression, and also a temperature control device.

The pressure vessel was made of hot galvanized carbon steel and piston was hard chrome-plated and polished to mirror finish (steel-type heat-treated special K) which was processed into the required sizes at the Electrical and Electronic Engineering Department of Middle East Technical University (Ankara, Turkey). The liquid was heated prior to pressurization to the desired temperature by an electrical heating system surrounding the chamber. Time to reach the desired pressure and also for depressurization was approximately 5–10 s for the system.

Physical and chemical analyses

Physical analyses

The colour of the fish samples was determined with the help of a Konica Minolta chromo meter (model CR 400/410; Minolta, Osaka, Japan). L^* (brightness), a^* (+ a, red; – a, green) and b^* (+ b, yellow; – b, blue) values were measured. The colorimeter was calibrated using white references (CR-A44). The colour was measured on homogenates prepared from ten fish fillets. The homogenate was placed in plastic petri dishes and the colour measurement was repeated 10 times. Averages and standard deviations of L^*, a^* and b^* values were calculated as the total colour differences. The total colour difference (E), as calculated below, was also used for evaluation, $E = (L^{*2} + a^{*2} + b^{*2})^{1/2}$ where L^*, a^* and b^* are the difference of the L^*, a^* and b^* values between the treated samples and control (Gerdes and Santos Valdez, 1991).

Chemical analysis

The thiobarbituric acid value was determined colorimetric by the method of Erkan and Özden (2008). Trimethylamin nitrogen was determined by the method of AOAC (1998). Results of TBA and TMA-N were expressed as mg/kg muscle and mg/100 g muscle. Free amino acid content of untreated and HP treated samples was determined using the hydrolysis and derivatization technique described by Erkan et al (2010). The amino acids were determined by using a (HPLC). In this study, it was determined that cold smoked salmon contained lysine (lys), methionine (meth), isoleucine (isoleu), leucine (leu), phenylalanine (phen), valine (val), histidin (his), serine (ser), arginine (arg), cysteine (cys), tyrosine (tyr), alanine (ala), aspartic acid (asp), glutamic acid (glut), glycine (gly) and proline (prol). Amino acids were identified by comparison of their retention time with those of an authentic standard (Pierce, Amino Acid Standard Hydrolyzate, Product No: 20078 20088 20089 1800180 NCI0180, Rockford, IL, USA) and their contents were calculated on a weight basis (mg/100g).

Statistical analysis

Significant differences between the samples (for colour, TBA and TMA-N analysis) were calculated by Excel XP 2003 by one-way analysis of variance (ANOVA) using a significance level of $P < 0.05$ by Tukey's honestly significant difference test. Calculations for free amino acid made were the mean, standard deviation, coefficients of variation in percent and F-setting the confidence level at 95 % test (Sümbüloğlu and Sümbüloğlu, 2002).

Results and discussion

Changes in the colour of rainbow trout samples were shown in Tables 1. L^* values of untreated rainbow trout samples were 57.57 ± 2.98, respectively. The pressurized rainbow trout fillets lost their transparency with an increase of the L^* values, indicative of the brightness, for both an increase of the pressure. They particularly appeared as cooked. This affected is accentuated with an increase in the pressure. The changes were attributed to the denaturation of the myofibriller and sarcoplasmic proteins. Similar results were reported for HP-treated carp (Sequeira-Munoz et al., 2006) and also for HP-treated mahi mahi, rainbow trout (Yağız et al., 2007), for HP- treated sea bream (Erkan and Üretener, 2010) and HP treated red mullet (Erkan et al., 2010).

The a* values, normally used as an index of visual redness, did not change significantly after pressurization in rainbow trout muscle (except 250 MPa, 7 °C for 10 min). Not significantly differences (p>0.05) in b* values were noted for rainbow trout flesh HP- treated compared to untreated rainbow trout's. It has been reported for mackerel and cod fish that the a* values decreased after pressurization (Ohshima et al., 1993). Similarly, redness of raw cod was lost after HP treatment at ≥ 200 MPa (Angsupanich et al., 1999). Chevalier et al. (2001) observed essentially no changes in the a* values with pressure or holding time. It has been reported for carp that the b* values increased with pressure and with holding times at pressure levels of 140 MPa and above (Sequeira- Munoz et al., 2006). Erkan et al. (2010) reported that a* and b* values of fresh red mullet were not affected after treatment at 250 MPa, 3–7–15–25 °C for 5 min.

The total colour differences (ΔE) between samples of pressurized sea food are reported as appropriate indicators for changes in colour (Chevalier et al., 2001). Minimum ΔE values were found in the following HP condition: 220 MPa, 15–25 °C for 10 min, 220 MPa, 7 °C for 5–10 min, 250 MPa, 7 °C for 5 min for rainbow trout. The total colour differences in the literature were reported as 6.6, 8.6 and 24.3 for muscles of pressurized carp fillets at 140 MPa, 4 °C for 15 and for 30 min and at 200 MPa, 4 °C for 30 min, respectively (Sequeira-Munoz et al., 2006); 5.9, 6.3, 20.3 and 24.3 for muscles of pressurized turbot fillets at 100 MPa, 4 °C for 15 and for 30 min and at 200 MPa, 4 °C for 15 and for 30 min, respectively (Chevalier et al., 2001).

The TBA values for rainbow trout samples of HP-treated samples (at 220, 250, 330 MPa, 7, 15, 25 °C for 5 min) were not significantly (p>0.05) different to those of untreated rainbow trout's; however, TBA values of HP-treated rainbow trout flesh were significantly (p < 0.05) lower than those of untreated rainbow trout samples (at 220, 250, 330 MPa, 7, 15, 25 °C for 10 min). In the literature, the TBA

TABLE 1: *Changes in colour analysis results of unpressurized and pressurized rainbow trout.*

Temperature/ Time		7 °C/ 5 min	7 °C/ 10 min	15 °C/ 5 min	15 °C/ 10 min	25 °C/ 5 min	25 °C/ 10 min
L*	Untreated	57.57^{Aa} ± 2.98*	57.57^{Aa} ± 2.98	57.57^{Aa} ± 2.98	57.57^{Aa} ± 2.98	57.57^{Aa} ± 2.98	57.57^{Aa} ± 2.98
	220 MPa	65.34^{Ba} ± 2.42	67.01^{Ba} ± 1.08	67.62^{Ba} ± 2.72	62.76^{Ba} ±1.66	65.32^{Ba} ± 1.93	64.62^{Ba} ± 3.03
	250 MPa	65.81^{Ba} ± 4.62	69.71^{Ba} ± 0.64	66.16^{Ba} ± 0.81	69.42^{Ca} ± 0.43	72.96^{Cb} ± 2.43	68.30^{Ba} ± 1.53
	330 MPa	73.99^{Ba} ± 5.03	70.53^{Ba} ± 1.39	72.02^{Ba} ± 1.29	72.08^{Ca} ± 3.05	75.21^{Ca} ± 4.13	75.52^{Ca} ± 2.32
a*	Untreated	2.88^{Aa} ± 0.91	2.88^{Aa} ± 0.91	2.88^{Aa} ± 0.91	2.88^{Aa} ± 0.91	2.88^{Aa} ± 0.91	2.88^{Aa} ± 0.91
	220 MPa	3.40^{Aa} ± 0.59	3.40^{Aa} ± 0.95	2.58^{Aa} ± 1.00	2.52^{Aa} ± 0.05	2.97^{Aa} ± 1.10	4.36^{Aa} ± 1.77
	250 MPa	2.47^{Aa} ± 1.80	1.25^{Bb} ± 0.34	2.84^{Aa} ± 0.44	2.02^{Aa} ± 1.14	2.22^{Aa} ± 1.59	2.84^{Aa} ± 0.69
	330 MPa	2.96^{Aa} ± 0.04	1.63^{Aa} ± 1.27	3.49^{Aa} ± 0.91	1.58^{Aa} ± 0.78	3.97^{Aa} ± 2.57	2.10^{Aa} ± 1.00
b*	Untreated	14.97^{Aa} ± 5.37	14.97^{Aa} ± 5.37	14.97^{Aa} ± 5.37	14.97^{Aa} ± 5.37	14.97^{Aa} ± 5.37	14.97^{Aa} ± 5.37
	220 MPa	13.77^{Aa} ± 3.36	15.25^{Aa} ± 1.95	14.21^{Aa} ± 1.49	12.96^{Aa} ± 1.50	12.12^{Aa} ± 0.90	16.61^{Aa} ± 2.59
	250 MPa	12.24^{Aa} ± 0.71	14.59^{Aa} ± 1.00	14.54^{Aa} ± 3.42	14.13^{Aa} ± 0.76	14.82^{Aa} ± 2.27	13.43^{Aa} ± 2.21
	330 MPa	14.07^{Aa} ± 0.75	13.47^{Aa} ± 0.12	15.92^{Aa} ± 4.31	13.73^{Aa} ± 0.98	14.35^{Aa} ± 2.72	13.83^{Aa} ± 0.20
E	Untreated	-	-	-	-	-	-
	220 MPa	8.33 ± 0.86	9.00 ± 1.44	10.62 ± 4.31	5.63 ± 0.77	8.44 ± 0.69	6.73 ± 3.46
	250 MPa	9.41 ± 4.84	11.72 ± 0.55	9.70 ± 3.56	11.52 ± 0.30	15.74 ± 3.73	11.19 ± 1.41
	330 MPa	17.07 ± 5.95	12.69 ± 1.49	15.22 ± 4.79	14.14 ± 3.13	18.14 ± 2.85	17.46 ± 2.33

* standard deviation (n = 3); Different letters (^{A}, ^{B}, ^{C}) in the same column indicate significant differences ($p < 0.05$); Different letters (^{a}, ^{b}, ^{c}) in the same line indicate significant differences ($p < 0.05$).

values of HP-treated fish and fish products with increasing pressure and pressure-holding times has been reported to show progressive changes (Sequeira-Munoz et al., 2006; Yağız et al., 2007). Angsupanich and Ledward (1998) reported that pressure below 400 MPa had a slight effect on lipid oxidation in cod muscle treated for 20 min at ambient temperature. However, they did not notice a significant change of the TBA number at 200 MPa. Horse mackerel and rainbow trout not seemed to be more sensitive to applied pressure in term of lipid oxidation. TBA value in HP applications are affected pressure, time and temperature. Furthermore, in lipid oxidation play a key role the content of unsaturated fats in fish species, iron compounds and myoglobin, hemoglobin and ferritin content in meat and fish (Chevalier et al., 2001). Amanatidou et al. (2000) reported that TBA values of fresh Atlantic salmon were not affected after HP treatment up to 200 MPa. Chevalier et al. (2001) favourable to find changes in TBA levels in raw turbot muscles treated at 100–140 MPa, 4 °C for 15–30 min. Sequeira-Munoz et al. (2006) reported that 100 MPa pressure 4 °C temperature 15 min time had little effect on lipid oxidation of carp fillets while 140–180 and 400 MPa, 4 °C for 15 and 30 min had significant effect on lipid oxidation. Yağız et al. (2007) reported stable TBA value compared to control samples in rainbow trout dark muscle treated at 150 and 300 MPa, room temperature for 15 min. Erkan et al. (2010) reported that TBA values of raw red mullet were not affected after high pressure treatment at 220 MPa, 3 °C for 5–10 min, 250 MPa, 7–15–25 °C for 5 min and 330 MPa, 7–15 °C for 5–10 min. Changes in TBA values of pressurized sea bream samples at 220–250 MPa, 15–25 °C for 10 min were reported as minor changes than the control (Erkan and Üretener, 2010).

TABLE 2: *Changes in TBA analysis results of unpressurized and pressurized rainbow trout.*

Temperature/ Time		7 °C/ 5 min	7 °C/ 10 min	15 °C/ 5 min	15 °C/ 10 min	25 °C/ 5 min	25 °C/ 10 min
TBA (mgMDA/kg)	Untreated	2.77^{Aa} ± 0.15	2.77^{Aa} ± 0.14	2.77^{Aa} ± 0.15	2.77^{Aa} ± 0.14	2.77^{Aa} ± 0.15	2.77^{Aa} ± 0.14
	220 MPa	2.34^{Aa} ± 0.07	2.23^{Bb} ± 0.02	2.46^{Aa} ± 0.35	1.96^{Ba} ± 0.09	2.52^{Aa} ± 0.31	2.06^{Bb} ± 0.25
	250 MPa	2.40^{Aa} ± 0.43	2.18^{Bb} ± 0.03	2.36^{Aa} ± 0.42	2.30^{Aa} ± 0.46	2.39^{Aa} ± 0.54	1.98^{Bb} ± 0.42
	330 MPa	2.31^{Aa} ± 0.30	2.30A^{Ba} ± 0.32	2.44^{Aa} ± 0.25	2.18^{Ba} ± 0.29	2.30^{Aa} ± 0.38	2.00^{Ba} ± 0.42

* standard deviation (n = 3); Different letters (^{A}, ^{B}, ^{C}) in the same column indicate significant differences ($p < 0.05$); Different letters (^{a}, ^{b}, ^{c}) in the same line indicate significant differences ($p < 0.05$).

TMA-N content is often used as a biochemical index to assess keeping quality and shelf-life of fish. In marine fish, TMA-N is formed from trimethylamine oxide (TMAO) which is a part of the non-protein nitrogen fraction of the fish flesh. TMA production is the result of bacterial enzyme activity and is the main compound responsible for an unpleasant "fishy" odour. The volatile amines trimethylamine (TMA-N) have been widely proposed as quality indicators in fish since they show a close relationship with the sensory score (Huss, 1995; Pons-Sánchez-Cascado et al., 2006). Study, we tested all the HP reconditions was found suitable for stability of TMA-N. On the other hand, there has been little data available documenting the TMA-N content of pressurized fish in literature. TMA-N content of pressurized rainbow trout are shown in Tables 3, respectively. TMA-N content of HP-treated at 250 MPa, 7 °C for 10 min, 250–330 MPa, 15 °C for 5 min, 250–330 MPa, 25 °C for 5 min, 220–250–330 MPa, 25 °C for 10 min rainbow trout samples were found to be significantly ($P < 0.05$) lower than the untreated samples. The changes were attributed to the inhibition of proteolytic activity (Hernández-Andrés et al. 2005). The effect of HP treatment on colour, TBA and TMA parameters of red mullet was studied by Erkan et al. (2010). These studies indicated unchanged TMA-N content for HP treated at 220 °C MPa, 15 °C for 10 min, 220 °C MPa, 25 °C for 5 min, 250 °C MPa, 7–25 °C for 10 min, 330 °C MPa, 3 °C for 5 min. HP-induced changes in TMA-N values measured immediately after HP treatment (at 220–250–330 °C MPa, 7 and 15 °C for 5 min; at 330 °C, 3–7 °C for 10 min) in this study are in agreement with data previously reported for HP-treated sea bream samples (Erkan and Üretener, 2010).

Amino acids play an important role in human nutrition and also affect the sensory traits of food products. During the processing of foods, protein sources are treated with heat, pressure, oxidizing agents, organic solvents, alkalis and acids for a variety of reasons. Such treatments may cause modification of the nutritional value of proteins, decreasing the amino acid content through desulfuration, deamination or isomerization; reactions with lysine, methionine, cystine and tryptophan are the most susceptible to damage (Belitz and Grosch, 1999; De la Cruz-García et al., 2000). Sea foods are rich in lysine, isoleucine, leucine and valine of the essential amino acids; these amino acids are for the development of both desirable and undesirable flavours in marine based food products. However, non-essential amino acids of sea foods, such as glutamic acid, aspartic acids also contribute to the characteristic taste and flavour of rainbow trout's (Özden, 2005).

In this study, glutamic acid, aspartic acid, lysine, leucine, arginine and valine content of untreated trout samples was found highly. Rainbow trout tissue HP-treated at at 220–250 MPa, 7–15 °C for 5–10 min and 330 MPa, 15–25 °C for 10 min did not differ significantly in the majority of amino acids compared to untreated rainbow trout tissue (Tab. 4). Amino acid contents of HP-trea-

TABLE 3: *Changes in TMA-N analysis results of unpressurized and pressurized rainbow trout.*

Temperature/ Time		7 °C/ 5 min	7 °C/ 10 min	15 °C/ 5 min	15 °C/ 10 min	25 °C/ 5 min	25 °C/ 10 min
TMA-N (mg/100 g)	Untreated	1.60^{Aa} ± 0.44	1.60^{Aa} ± 0.44	1.60^{Aa} ± 0.44	1.60^{Aa} ± 0.44	1.60^{Aa} ± 0.44	1.60^{Aa} ± 0.44
	220 MPa	1.44^{Aa} ± 0.34	1.59^{Aa} ± 0.07	1.15^{Aa} ± 0.28	1.74^{Aa} ± 0.09	1.12^{Aa} ± 0.57	0.50^{Bb} ± 0.14
	250 MPa	1.51^{Aa} ± 0.18	0.48^{Bb} ± 0.14	0.50^{Bb} ± 0.03	2.05^{Ac} ± 0.06	1.15^{Bd} ± 0.06	0.35^{Bb} ± 0.11
	330 MPa	1.52^{Aa} ± 0.13	1.81^{Aa} ± 0.53	0.97^{Bb} ± 0.18	1.73^{Aa} ± 0.11	1.17^{Bb} ± 0.07	0.95^{Cb} ± 0.06

* standard deviation (n = 3), Different letters (^{A}, ^{B}, ^{C}) in the same column indicate significant differences ($p < 0.05$) Different letters (^{a}, ^{b}, ^{c}) in the same line indicate significant differences ($p < 0.05$).

TABLE 4: *Changes in free amino acid analysis results of unpressurized and pressurized rainbow trout (insignificant data compared to control are shown with dark colour).*

Amino acids (mg/100g)	C	220 MPa, 7 °C, 5 min	220 MPa, 7 °C, 10 min	250 MPa, 7 °C, 5 min	250 MPa, 7 °C, 10 min	330 MPa, 7 °C, 5 min	330 MPa, 7 °C, 10 min	220 MPa, 15 °C, 5 min	220 MPa, 15 °C, 10 min	250 MPa, 15 °C, 5 min	250 MPa, 15 °C, 10 min	330 MPa, 15 °C, 5 min	330 MPa, 15 °C, 10 min	220 MPa, 25 °C, 5 min	220 MPa, 25 °C, 10 min	250 MPa, 25 °C, 5 min	250 MPa, 25 °C, 10 min	330 MPa, 25 °C, 5 min	330 MPa, 25 °C, 10 min
Lys	2111 ±15.99	1941 ±8.90	1927 ±2.15	1877 ±8.08	**1933 ±8.17**	**1950 ±7.27**	2076 ±18.31	1739 ±9.06	1813 ±32.94	1872 ±10.42	1763 ±6.12	1528 ±6.41	1932 ±17.64	1834 ±8.87	**2274 ±28.33**	**2240 ±0.85**	**2039 ±5.14**	2471 ±7.02	**2243 ±5.19**
Meth	683 ±1.73	701 ±2.04	786 ±2.17	715 ±0.63	623 ±2.87	758 ±5.67	832 ±6.18	**687 ±7.55**	**711 ±7.66**	**728 ±11.88**	**728 ±0.02**	718 ±2.02	729 ±5.12	645 ±1.37	836 ±12.14	888 ±9.10	746 ±3.50	957 ±2.20	735 ±1.92
Thre	971 ±3.11	**932 ±9.33**	930 ±4.30	901 ±3.75	916 ±3.11	**1065 ±8.74**	**990 ±4.16**	901 ±1.21	**877 ±20.74**	872 ±1.17	938 ±4.61	921 ±1.31	889 ±6.93	847 ±2.45	1122 ±1.80	1080 ±9.88	1079 ±0.10	1180 ±0.05	1007 ±0.65
Isoleu	1131 ±8.12	**1188 ±9.69**	1143 ±0.65	1057 ±8.50	**1042 ±15.97**	1309 ±2.43	1269 ±14.01	**1039 ±2.26**	1071 ±10.94	1039 ±2.66	1119 ±17.43	**1102 ±0.80**	**1139 ±11.22**	1061 ±4.27	1305 ±8.81	1203 ±5.63	1232 ±1.80	1374 ±5.30	**1195 ±0.24**
Leu	1692 ±5.81	**1671 ±4.43**	1637 ±0.65	**1548 ±6.66**	**1536 ±11.93**	1795 ±3.38	1774 ±13.19	1491 ±11.32	1516 ±9.14	1524 ±10.74	1607 ±1.10	1567 ±5.87	1600 ±2.81	1520 ±7.26	1902 ±0.75	1837 ±0.08	1807 ±3.65	2032 ±4.39	1793 ±6.84
Phen	978 ±2.84	**1001 ±3.37**	**985 ±3.66**	**925 ±7.29**	910 ±9.68	1108 ±4.76	1052 ±0.23	**909 ±4.78**	887 ±1.28	911 ±4.30	946 ±1.76	1064 ±1.60	**961 ±5.03**	**917 ±4.90**	1129 ±3.01	1102 ±2.65	1040 ±6.25	1215 ±1.24	1067 ±1.40
Val	1264 ±15.81	**1350 ±8.87**	**1283 ±4.26**	**1166 ±0.14**	1153 ±11.22	1511 ±3.60	**1418 ±18.95**	**1165 ±2.57**	**1209 ±28.36**	**1146 ±4.72**	**1257 ±14.54**	**1234 ±3.55**	**1285 ±10.21**	**1196 ±6.41**	**1423 ±7.29**	**1320 ±6.80**	**1411 ±4.137**	1496 ±2.85	**1337 ±0.12**
His	626 ±2.289	641 ±1.35	**638 ±6.99**	**588 ±7.77**	**595 ±6.11**	814 ±6.09	686 ±4.80	**602 ±4.06**	**588 ±5.25**	553 ±0.42	**609 ±1.89**	**672 ±6.36**	**635 ±0.15**	**593 ±3.16**	730 ±3.10	694 ±1.32	773 ±12.26	779 ±1.35	**676 ±3.35**
Ser	833 ±0.65	890 ±2.75	**852 ±6.39**	**832 ±2.69**	795 ±0.084	1650 ±4.72	814 ±1.05	**851 ±1.44**	737 ±6.25	**795 ±4.97**	**846 ±6.63**	**787 ±5.87**	764.02 ±4.09	776 ±0.91	989 ±3.13	945 ±1.98	1105 ±6.59	1019 ±8.92	890 ±5.01
Arg	1530 ±5.90	**1466 ±2.08**	**1429 ±8.94**	1343 ±1.70	**1352 ±21.34**	1429 ±14.30	**1500 ±6.77**	1331 ±0.41	1312 ±12.99	1285 ±6.54	1336 ±3.27	**1492 ±2.61**	**1404 ±19.30**	1354 ±5.50	1729 ±3.04	**1586 ±6.76**	1807 ±2.61	1752 ±3.41	**1580 ±9.57**
Cys	131 ±0.09	100 ±0.77	111 ±0.01	99 ±2.15	**130 ±1.20**	120 ±1.02	113 ±0.016	89 ±0.46	91 ±3.285	**112 ±2.03**	80 ±0.26	**137 ±2.02**	**119 ±2.18**	128 ±0.10	167 ±2.01	**130 ±1.23**	209 ±2.54	177 ±1.35	**131 ±1.28**
Tyr	808 ±5.84	**833 ±0.02**	**818 ±2.66**	767 ±1.76	750 ±0.55	985 ±3.18	867 ±0.38	803 ±0.94	764 ±1.48	**761 ±2.01**	**803 ±8.49**	893 ±2.23	**801 ±0.48**	770 ±6.72	948 ±1.48	920 ±10.17	969 ±1.19	985 ±0.69	**872 ±7.34**
Ala	1066 ±12.11	1265 ±8.02	1227 ±1.94	**1126 ±1.71**	**989 ±2.14**	1360 ±10.86	1355 ±7.64	1165 ±1.25	**1151 ±24.83**	**1110 ±5.30**	**1078 ±16.50**	966 ±4.29	1216 ±17.90	**1080 ±10.06**	1385 ±26.52	1347 ±0.57	1764 ±0.51	1506 ±3.95	**1108 ±3.39**
Asp	2319 ±10.16	**2020 ±8.46**	2109 ±0.18	2020 ±0.62	2110 ±4.72	2197 ±14.63	**2269 ±30.41**	1908 ±5.69	1889 ±28.41	1954 ±0.19	1863 ±26.01	1556 ±5.67	2058 ±10.92	1912 ±11.07	**2472 ±57.34**	**2392 ±19.83**	2028 ±7.56	2619 ±34.56	2463 ±3.23
Glut	3276 ±10.65	2838 ±5.55	2924 ±6.39	2789 ±12.59	2950 ±1.44	2837 ±7.29	**3141 ±36.47**	2634 ±2.25	2708 ±4.04	2785 ±34.14	2703 ±16.29	2288 ±4.33	2835 ±17.39	2680 ±11.37	**3458 ±47.13**	3312 ±11.80	2993 ±4.59	3664 ±5.90	3430 ±4.05
Gly	1014 ±3.84	1224 ±7.83	**1326 ±0.01**	996 ±1.75	936 ±4.32	1484 ±4.02	1112 ±3.74	**989 ±8.51**	**946 ±11.85**	915 ±2.50	**1032 ±9.55**	1128 ±1.66	1077 ±5.73	1008 ±5.17	1167 ±12.19	1154 ±3.10	1525 ±0.94	1240 ±1.50	1110 ±3.21
Prol	689 ±0.64	**731 ±6.06**	**670 ±13.14**	611 ±7.12	614 ±4.39	734 ±1.02	709 ±0.50	**662 ±8.18**	628 ±0.96	604 ±4.65	630 ±3.64	642 ±0.87	**642 ±10.25**	604 ±4.77	752 ±1.403	**701 ±10.19**	733 ±1.94	774 ±0.19	728 ±2.14

ted samples were lower or higher than untreated trout samples because of protein denaturation. Denaturation of protein by HP has been well reported. Pressure, temperature and exposure of HP treatment determine degree of protein denaturation. Sendra et al. (2000) has been reported the decrease of free amino acids in cheese treated pressures in over 200–300 MPa. This change in amino acid content may cause changes in the fish's flavour and aroma, this compounds may also reflect fish product quality during storage. Amino acid changes in the HP-treated fishes that may be associated with the image of the cooked. More detailed studies should be done about it. In this study, especially at low temperatures (7 °C) with increasing pressure and holding time of changes in amino acids were determined to increase. Similar situation was observed in the press room temperature (15 °C) applications. Amino acid changes of high pressure application at 7 and 15 °C is higher than the high pressure application at 25 °C.

In conclusion, rainbow trout were subjected to HP treatments at 220, 250 and 330 MPa, 7, 15 and 25 °C for 5 and 10 min. In the selection of the best HP conditions close to control values or lower than the control colour, TBA and TMA-N values were based and are assessed together. Colour, TMA-N and TBA results indicated that HP-treated rainbow trout used in this trial had a best condition HP of at 220 MPa, 7–15–25 °C for 5–10 min and 250 MPa, 7–15 °C for 5 min.

Acknowledgments

This work was supported by the TUBİTAK-TOVAG projects (No: 108O668) and the Research Found of Istanbul University (Project Number BYP-2861).

References

Angsupanich K, Ledward D A (1998): High pressure treatment effects on cod *(Gadus morhua)* muscle. Food Chem. 63, 39–50.

Angsupanich K, Edde M, Ledward DA (1999): Effects of high pressure on the myofibrillar proteins of cod and turkey muscle. J Agric Food Chem. 47, 92–99.

Amanatidou A, Schülüter O, Lemkau K, Gorris LGM, Smid EJ, Knorr D (2000): Effect of combined application of high pressure treatment and modified atmospheres on the shelf life of fresh Atlantic salmon. Innov Food Sci Emerg Technol. 1, 87–98.

AOAC (1998): AOAC Official Method 971.14, Trimethylamine Nitrogen in Seafood Colorimetric Method. In: Hungerford JM (Chapter ed). Fish and Other Marine Products. In: Cunniff, P. Eds. Official Methods of Analysis of AOAC International, Chapter 35, p 7.

Belitz HD, Grosch W (1999): Food Chemistry. Springer Verlag, Berlin, xliii+992 pages. ISBN: 3-540-64692-2.

Büyükcan M, Bozoğlu F, Alpas H (2009): Preservation and shelf-life extension of shrimps and clams by high hydrostatic pressure. Int J Food Sci. Technol. 44, 1495–1502.

Chevalier D, Le Bail A, Ghoul M (2001): Effects of high pressure treatment (100–200 MPa) at low temperature on turbot *(Scophthalmus maximus)* muscle. Food Res Int. 34, 425–429.

Council Directive 91/493/EEC of 22 July 1991 laying down the health conditions for the production and the placing on the market of fishery products. Off.). EC L268, 15–34.

Council Directive 86/609/EEC of 24 November 1986 on the approximation of laws, regulations and administrative provisions of the Member States regarding the protection of animals used for experimental and other scientific purposes. Offical Journal of the European Communities L358, 1–29.

Cruz-Romero M, Kerry JP, Kelly AL (2008a): Changes in the microbiological and physicochemical quality of high-pressure-treated oysters *(Crassostrea gigas)* during chilled storage. Food Cont. 19, 1139–1147.

Cruz-Romero M, Kerry JP, Kelly AL (2008b): Fatty acids, volatile compounds and colour changes in high-pressure-treated oysters *(Crassostrea gigas)*. Innov Food Sci Emerg Technol. 9, 54–61

Cruz-Romero M, Kelly AL, Kerry JP (2008c): Influence of packaging strategy on microbiological and biochemical changes in high-pressure-treated oysters *(Crassostrea gigas)*. J Sci Food Agric. 88, 2713–2723.

De la Cruz-García C, López-Hernández J, González-Castro MJ, Rodríguez-Bernaldo De Quirós AI, Simal-Lozano J (2000): Protein, amino acid and fatty acid contents in raw and canned sea urchin *(Paracentrotus lividus)* harvested in Galicia (NW Spain). J Sci Food Agric. 80, 1189–1192.

Erkan N, Özden Ö (2008): Quality assessment of whole and gutted sardine *(Sardine pilchardus)* stored in ice. Int J Food Sci Technol. 43(9), 1549–1559.

Erkan N, Üretener G (2010): The effect of high hydrostatic pressure on the microbiological, chemical and sensory quality of fresh gilthead sea bream *(Sparus aurata)*. Eur Food Sci Technol. 230 (4), 533–542.

Erkan N, Selçuk A, Özden Ö (2010): Amino acid and vitamin composition of raw and cooked horse Mackerel. Food Analytical Method. 3, 269–275.

Erkan N, Üretener G, Alpas H (2010): Effect of high pressure (HP) on the quality and shelf life of red mullet *(Mullus surmelutus)*. Innov Food Sci Emerg Technol. 11(2), 259–264.

Fernandez J, Perez-Alvarez JA, Fernandez-Lopez JA (1997): Thiobarbituric acid test for monitoring lipid oxidation in meat. Food Chem. 59, 345–353.

Gerdes DL, Santos-Valdez C (1991): Modified atmosphere packaging of commercial Pacific red snapper (*Sebastes entomelas, Sebastes flavidus* or *Sebastes godei*). Lebensmittel Wissens Technol. 24, 256–258.

He H, Adams RM, Farkas DF, Morrissey MT (2002): Use of High-pressure Processing for Oyster Shucking and Shelf-life Extension. J Food Sci. 67(2), 640–645.

Hernández-Andrés A, Gómez-Guillén C, Montero P, Pérez-Mateos M (2005): Partial Characterization of Protease Activity in Squid *(Todaropsis eblanae)* Mantle: Modification by High-pressure Treatment. J Food Sci. 70(4):C239–C245.

Hurtado JL, Montero P, Borderias J (2001): Chilled storage of pressurized octopus *(Octopus vulgaris)* muscle. J Food Sci. 66(3), 400–406.

Huss, HH (1995): Quality and quality changes in fresh fish, in FAO Fisheries Technical Paper 348, ed. by Huss HH. Technological Laboratory Ministry of Agriculture and Fisheries, Denmark.

Ohshima T, Ushio H, Koizumi C (1993): High-pressure processing of fish and fish products. Trends Food Sci Technol. 4, 370–375.

Özden Ö (2005): Changes in amino acid and fatty acid composition during shelf-life of marinated fish. J Sci Food Agric. 85(12), 2015–2020.

Pons-Sánchez-Cascado S, Veciana-Nogués MT, Mariné-Font SBA, Vidal-Carou, MC (2006): Use of volatile and non-volatile amines to evaluate the freshness of anchovies stored in ice. J Sci Food Agric. 86, 699–705.

Sequeira-Munoz A, Chevalier D, LeBail, A, Ramaswamy HS, Simpson BK (2006): Physicochemical changes induced in carp *(Cyprinus carpio)* fillets by high pressure processing at low temperature. Innov Food Sci Emerg Technol. 7, 13–18.

Sendra E, Saldo J, Capellas M, Guamis B (2000): Decrease of free amino acids in high- pressure treated cheese. High Pressure Res. 19, 33–36

Sümbüloğlu K, Sümbüloğlu V (2002): Biyoistatistik. 10. Baskı, p. 275, Hatipoğlu Basım ve Yayım San. Tic. Ltd. Sti. ISBN: 975-7527–12-2. Ankara.

Tülsner M (1994): Fischverarbeitung. Bd. 1 – Rohstoffeigenschaften von Fisch und Grundlagen der Verarbeitungsprozesse. ISBN: 3-86022-196-5. Hamburg: Behr's Verlag.

Yağız Y, Kristinsson HG, Balaban MO, Marshall MR (2007): Effect of high pressure treatment on the quality of rainbow trout *(Oncorhynchus mykiss)* and mahi mahi *(Coryphaena hippurus)*. J Food Sci. 72(9), C509–C515.

Address for correspondence:
Assoc. Prof. Dr. Nuray Erkan
Istanbul University, Faculty of Fisheries, Department of Seafood Processing and Quality Control
Ordu Cad. No: 200 34470 Laleli/ Istanbul – Turkey
Fax: +90 212 455 58 61
Tel.: +90 212 455 57 00/16415
E-Mail: nurerkan@istanbul.edu.tr

Innovative Food Science and Emerging Technologies 11 (2010) 259–264

Contents lists available at ScienceDirect

Innovative Food Science and Emerging Technologies

journal homepage: www.elsevier.com/locate/ifset

Effect of high pressure (HP) on the quality and shelf life of red mullet (*Mullus surmelutus*)

Nuray Erkan [a,*], Gonca Üretener [b], Hami Alpas [c]

[a] Istanbul University, Faculty of Fisheries, Department of the Seafood Processing and Quality Control. Ordu cad. No: 200 34470 Laleli, Istanbul, Turkey
[b] Istanbul University, Institute of Science, Department of Fisheries and Seafood Processing, Bozdoğan Kemeri cad. No: 6 İşitme Engelliler Okulu Yanı Vezneciler, Istanbul
[c] Food Engineering Departments, Middle East Technical University, 06531, Ankara, Turkey

ARTICLE INFO

Article history:
Received 30 October 2009
Accepted 3 January 2010

Editor Proof Received Date 14 January 2010

Keywords:
Red mullet
Fish
High pressure treatment
Quality
Shelf life

ABSTRACT

The effect of different temperature/time/pressure high hydrostatic pressure (HP) treatment on the quality and shelf life of red mullet were studied. Different high pressure treatments (at 3, 7, 15 and 25 °C, 5 to 10 min and 220, 250 and 330 MPa) were tested to establish the best processing conditions for the quality of red mullet. The effect of the process on the quality of the sample was examined by colour, Trimethylamine nitrogen (TMA-N) and Thiobarbituric acid number (TBA) analysis. Based on the results of the parameters, the best combinations of HP treatments were determined as 220 MPa/5 min/25 °C and 330 MPa/5 min/3 °C for red mullet. The effects of this combination treatment on sensory, chemical and microbiological properties of red mullet stored at 4 °C were studied. The results obtained from this study showed that the shelf life of untreated and HP treated stored at 4 °C, as determined by overall acceptability of sensory and microbiological data, are 12 days for untreated red mullet and 14 days for treated red mullet at 220 MPa for 5 min at 25 °C and 15 days for treated red mullet at 330 MPa for 5 min at 3 °C.

Industrial relevance: Fresh fish have short shelf life. HP treatment has shown to be an effective method to control pathogen and spoilage microorganisms in fish and fish products. However, high pressure treatment can promote colour and oxidation changes that could modify their sensory characteristics. The main objective of the first part of this study was to detect the best combination among the applied pressure (220, 250 and 330 MPa), temperature (3, 7, 15 and 25 °C) and time (5 and 10 min) combinations. The treatment ranges were chosen according to the unchanging colour, lower TBA value and TMA stability by HP and considering the economical aspects of HP processing. In the second part of the study, HP was applied on the selected samples and a shelf-life study was performed by measuring the changes in the quality parameters, of the samples throughout their storage. The storage conditions were set so as to achieve refrigeration handling (4 °C). Shelf-life estimation was performed according to the data obtained. HP (at 220 MPa for 5 min at 25 °C and at 330 MPa for 5 min at 3 °C) treatment is the most effective treatment for shelf-life extension as compared to non-treated red mullet.

1. Introduction

Red mullet (*Mullus surmelutus*) belongs to the *Mullidae* (goatfish) family. Red mullets are of great commercial value and are native species. Red mullets are preferred fresh and the shelf life of red mullet is important for consumers. Information on the quality and shelf life of red mullet stored in ice are available in literature (Özyurt, Kuley, Özkütük, & Özoğul, 2009). Most of them studied the quality and shelf life of mullet and similar species in ice and/or in cold 4 °C temperature, but results were not always in agreement. In particular the limit of acceptability for red mullet and similar fish species ranged from 6 to 11 days (Gökoğlu, Özden, & Erkan, 1998; Gennari, Tomaselli, & Cotrona, 1999; Sasi, Jeyasekaran, Shanmugam, & Jeya Shakila, 2003; Stamatis and Arkoudelos, 2007; Reza, Bapary, Ahasan, Islam, & Kamal, 2009).

Although initial attempts to apply high pressure (HP) technology to food processing date back to the late 19th century, the true potential of HP technology for the food industry was put at the end of the 1980 s. HP technology has since become one of the most popular subjects of study in food engineering and technology. The advantages of HP technology include minimal effects on flavour and nutritional attributes of the final products (Sequeria-Munoz, Chevalier, Lebabile, Ramaswamy, & Simpson, 2006). Some studies done on meat and fish have shown that HP may be a useful processing tool for such products (Ohshima, Ushio, & Koizumi, 1993). Chevalier, Le Bail, and Ghoul (2001) studied high pressure effects on the quality of turbot flesh, while Cruz-Romero, Smiddy, Hill, Kerr, and Kelly (2004) studied high pressure effects on the physicochemical characteristics of oysters during chilled storage.

* Corresponding author.
E-mail address: nurerkan@istanbul.edu.tr (N. Erkan).

1466-8564/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ifset.2010.01.001

Büyükcan et al. (2009) investigated preservation and shelf-life extension of shrimps and clams by high pressure, while Cruz-Romero, Kelly, and Kerry (2008a) studied high pressure effects on the microbiological quality of oysters during chilled storage. There is relatively limited information regarding the effects of HP on the sensory, chemical and microbiological quality of raw fishes.

The main objective of the first part of this study was to determine the influence of the different HP combinations (pressure: 220–250 and 330 MPa, temperature: 3–7–15 and 25 °C and time: 5 and 10 min) on the physicochemical properties of red mullet like colour, lipid oxidation and trimethylamine nitrogen stability. In the second part of the study, the effect of selected HP conditions on the shelf life of red mullet during storage at 4 °C is discussed.

2. Materials and methods

2.1. Samples

Samples were obtained from the Ankara fish market in January, 2009. Red mullets were stored in boxes with ice after catching and delivered to the laboratory in 24 h. The mean weight and length of the fish were 43.12 ± 9.94 g and 13.09 ± 1.18 cm, respectively. The fish were gutted, filleted and washed. 3 kg of samples were used for the experiment. Experiments were started about 26 h after the death of the fish. The fish were filleted, skinned and divided into portions of equal weight (15 g). The samples were covered with flexible plastic films to avoid direct contact between them and the pressure-transmitting fluid. Then they were pressurized at 220, 250 and 330 MPa at 3, 7, 15 and 25 °C for 5 and 10 min. Immediately after HHP treatment, samples were frozen to −30 °C until used for Trimethylamine nitrogen (TMA-N), 2-thibarbituric acid reactive substances (TBA) and colour measurement. Colour, TMA-N and TBA analysis results were considered collectively (control sample close to the value or lower L*, a*, b*, TMA-N and TBA values based) for red mullet HHP application for the best combination were determined. For each application was performed random sampling. 3 kg of samples were used for the second experiment. Samples were prepared as in the first experiment. Two group samples were pressurized at 220 MPa at 25 °C for 5 min and at 330 MPa at 3 °C for 5 min and then stored at 4 °C, and the third group samples (control) was stored directly at 4 °C without undergoing high pressure treatment. After treatment, samples were stored for 17 days at 4 °C. Samples were placed into oxygen permeable bags for the storage study. In each analysis day for each group, samples were taken at random from ten packaged samples (each packaged samples approximately 15 g).

2.2. HHP treatment and storage conditions of samples

HHP treatments were performed in a designed and constructed laboratory-scale unit (capacity: 30 cm^3, maximum pressure: 500 MPa). Water was used as the pressure-transmitting medium. The equipment consists of a pressure chamber of cylindrical design, two end closures, a means for restraining the end closures, a pressure pump and a hydraulic unit to generate high pressure for system compression, and also a temperature control device. The pressure vessel was made of hot galvanized carbon steel and the piston was hard chrome-plated and polished to mirror finish (steel-type heat-treated special K) which was processed into the required sizes at the Electrical and Electronic Engineering Department of the Middle East Technical University (Ankara, Turkey). The liquid was heated prior to pressurization to the desired temperature by an electrical heating system surrounding the chamber. Time to reach the desired pressure and also for depressurization was approximately 5–10 s for the system.

2.3. Analyses

2.3.1. Sensory analysis

The attributes of raw fish fillet were evaluated by a panel of five experienced judges on each day of sampling. Panellists were laboratory trained. Sensory evaluation was conducted in individual booths under controlled conditions of light, temperature and humidity. Sensory analysis was performed using the methods of Huss (1988). HHP treated and non-treated fish fillet were assessed on the basis of appearance, and odour characteristics using a nine point descriptive scale. A score of 10–9 indicated "very good" quality, a score of 8.9–8 "good quality", a score of 7.9–4 "acceptable quality", a score of 3.9–0 denoted as spoiled. On the day of each analysis for each parameter was calculated the average scores of panellists.

2.3.2. Colour measurement

The colour of the fish samples was determined with the help of a Konica Minolta chromo meter (Konica Minolta, Model CR 400/410, Japan). L^* (brightness), a^* (+a, red; −a, green) and b^* (+b, yellow; −b, blue) values were measured. The colorimeter was calibrated using white references (CR-A44). Three different fillet parts were measured in three different locations of each part. The average of these values for L^*, a^* and b^* parameters was calculated. Averages and standard deviations of L^*, a^* and b^* values were calculated as the total colour differences. The total colour difference (ΔE), as calculated below, was also used for evaluation, $\Delta E = (\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{1/2}$ where ΔL^*, Δa^*, and Δb^* are the difference of the L^*, a^*, and b^* values between treated samples and control (Gerdes & Santos Valdez, 1991).

2.3.3. Chemical analysis

The fish samples were analyzed in triplicate for proximate composition: lipid content of red mullet by acid hydrolysis method of AOAC 948.15 (AOAC, 1998a), moisture content by the Mattissek, Schnepel, and Steiner (1992) method, the ash content by the AOAC (1998b) method, and total crude protein by the Kjeldhal method (AOAC, 1998c).

1 g of each sample was blended with 10 mL distilled water. The pH of the fish homogenate was measured using the digital pH meter Hanna pH 211 (HANNA Instruments, Michigan, USA), standardized at pH 4.0 and 7.0 (Erkan, 2007). Total volatile basic nitrogen (TVB-N, mg/100 g fish flesh) was determined according to the method described by Antonacopoulos & Vyncke (1989). Trimethylamine nitrogen (TMA-N, mg/100 g fish flesh) was measured using the method of AOAC (1998d), while the method used by Erkan and Özden (2008) was followed for the 2-thibarbituric acid reactive substances measurements (TBARS, mg of MDA/kg of fish meat).

2.3.4. Microbiological analyses

Sample preparation: Fish flesh (25 g) obtained from each fillet, was transferred aseptically to a Stomacher bag (Seward Medical, London, UK) containing 225 mL of 0.1% sterile peptone water (Merck, Cat No: 107228) and homogenized in a stomacher (Stomacher, IUL Instrument, Spain) for 60 s.

Microbiological media and enumeration: Microbiological media and enumeration for microbial enumeration, 0.1 mL samples of serial dilutions (1:10, diluents, 0.1% peptone water) of fish homogenates were spread on the surface of dry media. Total viable counts (mesophilic aerobic bacteria) were determined using plate count agar (PCA, Merck, Cat No: 105463) after incubation for 24–48 h at 37 °C. Psychrotrophic bacteria were determined using plate count agar after incubation for 10 days at 7 °C (Baumgart, 1986). Results are expressed as a logarithm of colony forming units (log cfu) per gram of sample.

All chemical and microbiological analyses were carried out in triplicate.

Table 1
Changes of colour values of unpressurized and pressurized red mullet.[a]

Temperature/time		3 °C/5 min	3 °C/10 min	7 °C/5 min	7 °C/10 min	15 °C/5 min	15 °C/10 min	25 °C/5 min	25 °C/10 min
L^*	Control	$50.87^{Aa} \pm 2.67$	$50.87^{Aa} \pm 2.67$	$50.87^{Aa} \pm 2.67$	$50.87^{Aa} \pm 2.67$	$50.87^{Aa} \pm 2.67$	$50.87^{Aa} \pm 2.67$	$50.87^{Aa} \pm 2.67$	$50.87^{Aa} \pm 2.67$
	220 MPa	$56.11^{Ba} \pm 1.04$	$66.20^{Bb} \pm 2.57$	$56.93^{Ba} \pm 2.58$	$63.74^{Bc} \pm 0.97$	$52.89^{Ba} \pm 3.54$	$52.34^{Aa} \pm 0.59$	$55.04^{Ba} \pm 1.81$	$56.87^{Ba} \pm 4.18$
	250 MPa	$65.71^{Ca} \pm 3.30$	$63.9^{Ba} \pm 3.22$	$65.80^{Ca} \pm 2.64$	$64.50^{Ba} \pm 1.39$	$57.63^{Bb} \pm 2.86$	$54.44^{Bb} \pm 1.74$	$57.89^{Bb} \pm 2.18$	$64.63^{Ca} \pm 1.64$
	330 MPa	$63.41^{Ca} \pm 1.10$	$59.70^{Ba} \pm 2.65$	$68.64^{Cb} \pm 1.52$	$64.53^{Ba} \pm 1.39$	$61.34^{Ca} \pm 2.22$	$66.90^{Ca} \pm 2.32$	$65.19^{Ca} \pm 4.91$	$66.27^{Ca} \pm 2.29$
a^*	Control	$4.36^{Aa} \pm 1.44$	$4.36^{Aa} \pm 1.44$	$4.36^{Aa} \pm 1.44$	$4.36^{Aa} \pm 1.44$	$4.36^{Aa} \pm 1.44$	$4.36^{Aa} \pm 1.44$	$4.36^{Aa} \pm 1.44$	$4.36^{Aa} \pm 1.44$
	220 MPa	$5.92^{Aa} \pm 1.74$	$2.46^{Bb} \pm 0.27$	$1.66^{Bc} \pm 0.90$	$3.47^{Ad} \pm 0.79$	$6.33^{Ba} \pm 1.48$	$4.80^{Aa} \pm 0.45$	$2.91^{Bb} \pm 0.26$	$2.89^{Bb} \pm 0.82$
	250 MPa	$4.24^{Aa} \pm 1.78$	$3.45^{Aa} \pm 1.26$	$3.38^{Aa} \pm 1.51$	$4.10^{Aa} \pm 0.20$	$3.10^{Aa} \pm 0.30$	$6.17^{Bb} \pm 2.39$	$3.76^{Aa} \pm 0.94$	$2.55^{Bc} \pm 0.14$
	330 MPa	$3.83^{Aa} \pm 1.17$	$2.09^{Ba} \pm 1.54$	$2.28^{Ca} \pm 0.12$	$1.02^{Bb} \pm 0.44$	$3.21^{Aa} \pm 0.57$	$2.84^{Ca} \pm 0.89$	$3.80^{Aa} \pm 0.85$	$2.56^{Ba} \pm 0.13$
b^*	Control	$10.34^{Aa} \pm 1.17$	$10.34^{Aa} \pm 1.17$	$10.34^{Aa} \pm 1.17$	$10.34^{Aa} \pm 1.17$	$10.34^{Aa} \pm 1.17$	$10.34^{Aa} \pm 1.17$	$10.34^{Aa} \pm 1.17$	$10.34^{Aa} \pm 1.17$
	220 MPa	$12.03^{Aa} \pm 2.00$	$10.41^{Ab} \pm 0.40$	$8.90^{Ab} \pm 1.32$	$9.00^{Ab} \pm 1.19$	$13.89^{Aa} \pm 1.03$	$10.66^{Ab} \pm 0.74$	$9.21^{Ab} \pm 0.39$	$8.66^{Ab} \pm 1.15$
	250 MPa	$13.79^{Ba} \pm 0.51$	$8.38^{Ab} \pm 1.31$	$9.66^{Ab} \pm 1.08$	$10.16^{Ac} \pm 1.04$	$10.93^{Ac} \pm 2.12$	$12.65^{Ba} \pm 3.29$	$10.26^{Ac} \pm 0.86$	$9.26^{Ab} \pm 0.65$
	330 MPa	$8.99^{Aa} \pm 1.84$	$7.73^{Aa} \pm 2.16$	$8.19^{Ba} \pm 0.54$	$6.94^{Bb} \pm 2.92$	$8.95^{Aa} \pm 0.38$	$7.09^{Ca} \pm 0.75$	$10.72^{Ac} \pm 0.86$	$9.11^{Aa} \pm 1.25$
ΔE	Control	–	–	–	–	–	–	–	–
	220 MPa	$6.94^{Aa} \pm 1.15$	$15.61^{Ab} \pm 1.10$	$6.94^{Aa} \pm 2.82$	$13.19^{Ac} \pm 1.10$	$6.08^{Aa} \pm 1.10$	$2.07^{Ad} \pm 0.33$	$3.91^{Ae} \pm 1.10$	$6.58^{Aa} \pm 4.26$
	250 MPa	$15.61^{Ba} \pm 3.01$	$13.50^{Aa} \pm 1.10$	$15.22^{Ba} \pm 2.76$	$13.84^{Aa} \pm 1.10$	$7.36^{Ab} \pm 2.93$	$5.84^{Bc} \pm 1.10$	$7.31^{Bb} \pm 1.10$	$14.08^{Ba} \pm 1.60$
	330 MPa	$12.45^{Ba} \pm 1.86$	$9.74^{Bb} \pm 1.10$	$18.17^{Bc} \pm 1.50$	$14.86^{Ad} \pm 1.10$	$10.78^{Ba} \pm 1.10$	$16.44^{Ce} \pm 1.10$	$14.57^{Cd} \pm 1.10$	$15.72^{Be} \pm 2.31$

Different letters ($^{A, B, C}$) in the same column indicate significant differences ($p<0.05$).
Different letters ($^{a, b, c}$) in the same line indicate significant differences ($p<0.05$).
[a] All values are the mean ± standard deviation ($n=3$).

2.3.5. Statistical analysis

The experiments were repeated twice. The measurements were run in triplicates for each replicate ($n=2\times3$). The results were reported as mean values ± standard deviation. The Tukey's honestly significant difference test was employed to find out the significance between different treatments and days of storage. The differences between the means were considered significant when $p<0.05$ (Sümbüloğlu & Sümbüloğlu, 2002).

3. Results and discussion

3.1. Proximate composition

The moisture, protein, lipid, and ash contents in red mullet were found to be 68.90%, 16.00%, 12.44%, and 1.86%, respectively. There was a little difference in the proximate composition of red mullet compared with the findings of Gökoğlu et al. (1998).

3.2. Effect of high pressure conditions on the quality of red mullet

Generally, significant differences ($p<0.05$) in L^*, a^* and b^* values were noted for HP treated red mullet tissue (Table 1). The L^* values of red mullet tissue increased with increasing treatment pressure (observed for each temperature). Untreated red mullets had the lowest L^*-values, indicating that HP treatment gave the mullet tissue a brighter and less transparent appearance. No significant differences ($p>0.05$) in L^* values were noted for red mullet tissue HP treated at 220 MPa for 15 min at 10 °C compared with untreated red mullets.

Significant ($p<0.05$) decreases in a^* values (redness) of pressurized red mullet tissue were found fallowing HP condition: 220–330 MPa/3 °C/10 min, 220–330 MPa/7 °C/5 min, 220 MPa/25 °C/5–10 min, 330 MPa/7–15–25 °C/10 min. a^* values of pressurized red mullet at 220 MPa for 5 min at 15 °C and 250 MPa for 10 min at 15 °C were significantly higher ($p<0.05$) than those found in unpressurized samples. The b^* values (yellowness) of red mullet tissue were also affected after HP treatment. Significant differences ($p<0.05$) in b^* values were noted for red mullet tissue HP treated at 250 MPa for 5 min at 3 °C, at 250 MPa for 10 min at 15 °C, 330 MPa for 5–10 min at 7 °C, and 330 MPa for 10 min at 15 °C compared with untreated red mullets (Table 1).

An increased L^* and b^* value and decreased a^* value as pressure is increased have been reported for different seafood species such as bluefish (Matser, Stegeman, Kals, & Bartels, 2000), cod (Angsupanich & Ledward, 1998), mackerel (Ohshima et al., 1993), salmon (Amanatidou et al., 2000), sheaphead (Ashie, Smith, & Simpson, 1996), turbot (Chevalier et al., 2001), carp (Sequeria-Munoz et al., 2006) and trout (Yağız, Kristinsson, Balaban, & Marshall, 2007) and salmon (Yağız et al., 2009). The total colour differences (ΔE) also reflected the progressive colour changes with increasing pressure and pressure-holding times, similar to the observations made by Chevalier et al. (2001).

TMA-N content is often used as a biochemical index to assess keeping quality and shelf life of fish. In marine fish, as red mullet, TMA is formed from trimethylamine oxide (TMAO) which is a part of the non-protein nitrogen fraction of the fish flesh. TMA production is the result of bacterial enzyme activity and is the main compound responsible for an unpleasant "fishy" odour (Debevere & Boskou, 1996; Gram & Huss, 1996). Table 2 gives the TMA content of unpressurized and pressurized red mullet. Usually, the TMA values of pressurized red mullet were significantly higher ($p<0.05$) than those found in unpressurized

Table 2
Changes of TMA-N and TBA contents of unpressurized and pressurized red mullet.[a]

Temperature/time		3 °C/5 min	3 °C/10 min	7 °C/5 min	7 °C/10 min	15 °C/5 min	15 °C/10 min	25 °C/5 min	25 °C/10 min
TMA-N(mg/100 g)	Untreated	$2.81^{Aa} \pm 0.19$	$2.81^{Aa} \pm 0.19$	$2.81^{Aa} \pm 0.19$	$2.81^{Aa} \pm 0.19$	$2.81^{Aa} \pm 0.19$	$2.81^{Aa} \pm 0.19$	$2.81^{Aa} \pm 0.19$	$2.81^{Aa} \pm 0.19$
	220 MPa	$3.92^{Ba} \pm 0.08$	$3.64^{Ba} \pm 0.15$	$3.84^{Ba} \pm 0.08$	$3.76^{Ba} \pm 0.04$	$5.66^{Bb} \pm 0.23$	$3.11^{Ac} \pm 0.21$	$2.92^{Ad} \pm 0.13$	$3.88^{Ba} \pm 0.23$
	250 MPa	$4.00^{Ba} \pm 0.07$	$3.80^{Ca} \pm 0.06$	$3.73^{Bb} \pm 0.04$	$3.09^{Ac} \pm 0.07$	$3.76^{Cb} \pm 0.24$	$3.85^{Ba} \pm 0.27$	$3.55^{Bb} \pm 0.14$	$2.83^{Ad} \pm 0.07$
	330 MPa	$2.91^{Aa} \pm 0.06$	$3.66^{Bb} \pm 0.06$	$3.51^{Bb} \pm 0.05$	$3.79^{Bb} \pm 0.16$	$4.45^{Dc} \pm 0.05$	$3.70^{Bb} \pm 0.09$	$3.97^{Cd} \pm 0.10$	$3.55^{Cb} \pm 0.10$
TBA (mg MDA/kg)	Untreated	$1.53^{Aa} \pm 0.04$	$1.53^{Aa} \pm 0.04$	$1.53^{Aa} \pm 0.04$	$1.53^{Aa} \pm 0.04$	$1.53^{Aa} \pm 0.04$	$1.53^{Aa} \pm 0.04$	$1.53^{Aa} \pm 0.04$	$1.53^{Aa} \pm 0.04$
	220 MPa	$1.54^{Aa} \pm 0.02$	$1.61^{Aa} \pm 0.03$	$1.93^{Bb} \pm 0.13$	$1.83^{Bc} \pm 0.05$	$1.78^{Bc} \pm 0.06$	$1.82^{Bc} \pm 0.10$	$1.42^{Aa} \pm 0.07$	$1.38^{Bd} \pm 0.05$
	250 MPa	$1.71^{Ba} \pm 0.01$	$1.78^{Ba} \pm 0.03$	$1.64^{Ab} \pm 0.06$	$1.53^{Ab} \pm 0.03$	$1.55^{Ab} \pm 0.03$	$1.79^{Ca} \pm 0.05$	$1.58^{Ab} \pm 0.05$	$1.43^{Cc} \pm 0.05$
	330 MPa	$1.66^{Aa} \pm 0.05$	$1.73^{Bb} \pm 0.07$	$1.53^{Ac} \pm 0.09$	$1.68^{Aa} \pm 0.06$	$1.55^{Ac} \pm 0.06$	$1.66^{Aa} \pm 0.09$	$3.01^{Bd} \pm 0.09$	$1.45^{Ce} \pm 0.04$

Different letters ($^{A, B, C}$) in the same column indicate significant differences ($p<0.05$).
Different letters ($^{a, b, c}$) in the same line indicate significant differences ($p<0.05$).
[a] All values are the mean ± standard deviation ($n=3$).

Table 3
Changes of sensory values of unpressurized and pressurized red mullet stored at 4 °C.[a]

Storage days		1	3	5	7	9	11	13	15	17
Appearance	Control	$9.00^{Aa} \pm 0.00$	$8.00^{Ab} \pm 0.00$	$7.20^{Ac} \pm 0.14$	$6.00^{Ac} \pm 1.41$	$4.00^{Ad} \pm 0.00$	$3.50^{Ad} \pm 0.71$	$2.50^{Ae} \pm 0.71$	$1.50^{Ae} \pm 0.71$	$0.85^{Af} \pm 0.21$
	3 °C 5 min 330 MPa	$9.00^{Aa} \pm 0.00$	$9.00^{Aa} \pm 0.00$	$8.35^{Bb} \pm 0.49$	$6.00^{Ac} \pm 0.00$	$5.00^{Bd} \pm 0.71$	$4.70^{Ae} \pm 0.99$	$3.50^{Af} \pm 0.71$	$2.50^{Ag} \pm 0.71$	$1.50^{Ag} \pm 0.71$
	25 °C 5 min 220 MPa	$9.00^{Aa} \pm 0.00$	$8.55^{Ab} \pm 0.07$	$8.15^{Bb} \pm 0.49$	$6.25^{Ac} \pm 1.06$	$5.00^{Bd} \pm 0.71$	$4.50^{Bd} \pm 0.00$	$3.75^{Ae} \pm 1.06$	$2.00^{Af} \pm 0.00$	$1.00^{Af} \pm 0.00$
Odour	Control	$9.35^{Aa} \pm 0.21$	$8.00^{Ab} \pm 0.00$	$6.75^{Ac} \pm 1.06$	$4.85^{Ad} \pm 0.21$	$3.50^{Ae} \pm 2.12$	$3.50^{Ae} \pm 0.71$	$2.00^{Af} \pm 0.00$	$1.50^{Af} \pm 0.71$	$1.10^{Af} \pm 0.00$
	3 °C 5 min 330 MPa	$9.35^{Aa} \pm 0.21$	$8.75^{Ab} \pm 0.35$	$8.25^{Bb} \pm 0.35$	$6.25^{Bc} \pm 1.77$	$4.50^{Ad} \pm 0.71$	$3.25^{Ae} \pm 0.35$	$3.00^{Ae} \pm 0.00$	$3.00^{Be} \pm 0.71$	$1.00^{Af} \pm 0.00$
	25 °C 5 min 220 MPa	$9.35^{Aa} \pm 0.21$	$7.50^{Ab} \pm 0.71$	$7.50^{Ab} \pm 0.71$	$5.75^{Bc} \pm 0.35$	$4.25^{Ad} \pm 1.06$	$3.75^{Ae} \pm 0.35$	$3.50^{Ae} \pm 0.71$	$2.75^{Bf} \pm 0.35$	$1.00^{Af} \pm 0.00$

Different letters ($^{A, B, C}$) in the same column indicate significant differences ($p<0.05$).
Different letters ($^{a, b, c}$) in the same line indicate significant differences ($p<0.05$).
[a] All values are the mean ± standard deviation ($n=3$).

samples. The TMA value of red mullet tissue was also not affected after treatment at 330 MPa for 5 min at 3 °C, 250 MPa for 10 min at 7 °C, 220 MPa for 10 min at 15 °C and 220 MPa for 5 min at 25 °C.

The TBA value in the pressurized samples at 3 and 25 °C for 5 and 10 min regularly increased ($p<0.05$) with pressure. The TBA values of pressurized samples at 7 and 15 °C for 5 and 10 min were significantly higher ($p<0.05$) than those found in unpressurized samples, except HP treated at 330 MPa for 5–10 min at 7–15 °C and 250 MPa for 5 min at 7–15 °C (Table 2). Similarly, for a given pressure level, the TBA value increased as processing time increased. Similar results were reported for HP treated carp tissue and rainbow trout (Sequeria-Munoz et al., 2006; Yağız et al., 2007).

The result of this study indicates that the best conditions of HP treated red mullet stored at 4 °C as determined by the overall acceptability data (control samples close to L^*, a^*, and b^*, control samples close or lower to the TBA and TMA-N values based on) are 220 MPa for 5 min at 25 °C and 330 MPa for 5 min at 3 °C, respectively. Erkan and Üretener (2010) found that the optimum HP conditions for sea bream (*Sparus aurata*) was 250 MPa/5 min/3 °C and 250 MPa/ 5 min/ 5 °C, which result in a shelf life of about 18 days at 4 °C (from 15 days).

3.3. Shelf life of HP treated red mullet

The results of the sensory evaluation of untreated and HP treated red mullet samples are presented in Table 3. As the results show up to ca. 11 days of storage all lots of HP treated red mullet samples received an appearance score significantly higher than or similar to (control samples) the lower acceptability limit of 4. HP treated samples reached this limit after 13 days. On the other hand, the odour of all HP treated samples received scores above the acceptability limit of 4, up to 11 days. Based on appearance and odour scores the shelf life of ca. 12 days achieved for HP treated samples corresponds to a ca. 2 days extension of the shelf life in comparison with control samples. Similar results for assessment of shelf life of same fish species have been reported. Sasi et al. (2003) reported a shelf life for seer fish (*Scomberomorus commersonii*) of 11 days, while Özyurt et al. (2009) reported a shelf life for gold band goatfish (*Upeneus moluccensis*) and for red mullet (*Mullus barbatus*) stored in ice of 8 and 11 days. High hydrostatic pressure (HHP) treatment, in combination with good refrigeration and handling practices, provides a means to increase fish product shelf life. Zare (2004) determined the effect of HP (at 200 MPa for 30 min and 220 MPa 30 min) on microbiological, chemical, and sensory properties of tuna stored in a refrigerator. Results of this study indicate that the shelf life of HP treated and untreated tuna stored in a refrigerator as determined by the overall acceptability sensory scores is 18 and 6 days, respectively. The storage life of HP treated fish is affected by the initial microbial load of the fish, micro flora, packaging material, storage temperature and packing methods (Cruz-Romero, Kelly, & Kerry 2008b).

At the beginning of the storage period, L^* values of untreated and treated red mullet were determined as 50.90 ± 1.5, 53.10 ± 0.70, and 52.60 ± 0.30. At the end of the storage period of 14 days, L^* values of untreated and treated red mullet increased to 53.60 ± 1.0 and 64.40 ± 0.80, 59.9 ± 0.50. a^* and b^* values of all group samples were determined fluctuation during the cold storage (Table 4). Similar results were reported for HP treated rainbow trout, mahi mahi and salmon (Yağız et al., 2007, 2009).

pH values of the untreated and treated (at 220 MPa for 5 min at 25 °C) samples reached the values of 7.1 ± 0.1 and 7.0 ± 0.3 after 13 days of storage, exceeding the upper acceptability limit set by Ludorff and Meyer (1973) for pH values of fish (score 7) after ca. 13 days of storage. The pH values of HP treated (at 330 MPa for 5 min at 3 °C) red mullet samples exceeded this limit after 17 days respectively.

The initial (day 1) TVB-N values of 22.8 ± 0.3 and 13.8 ± 0.2–19.9 ± 0.3 mg/100 g are of the same order of magnitude with the values of

Table 4
Changes of colour values of unpressurized and pressurized red mullet stored at 4 °C.[a]

Storage days		1	3	5	7	9	11	13	15	17
L^*	Control	$50.9^{Aa} \pm 1.5$	$51.9^{Aa} \pm 1.5$	$53.7^{Aa} \pm 2.2$	$53.6^{Aa} \pm 1.8$	$55.2^{Ab} \pm 1.7$	$57.9^{Ac} \pm 1.7$	$49.7^{Aa} \pm 1.1$	$62.5^{Ad} \pm 1.7$	$53.6^{Aa} \pm 1.0$
	3 °C 5 min 330 MPa	$53.1^{Aa} \pm 0.7$	$54.2^{Aa} \pm 0.9$	$53.2^{Aa} \pm 1.6$	$55.3^{Ab} \pm 0.8$	$53.4^{Aa} \pm 2.0$	$59.3^{Ac} \pm 1.3$	$52.0^{Ba} \pm 0.3$	$57.7^{Bd} \pm 1.3$	$64.4^{Be} \pm 0.7$
	25 °C 5 min 220 MPa	$52.6^{Aa} \pm 0.3$	$53.9^{Aa} \pm 0.1$	$50.3^{Aa} \pm 0.5$	$55.9^{Ab} \pm 1.5$	$56.3^{Ac} \pm 1.5$	$55.9^{Ab} \pm 0.9$	$52.1^{Ba} \pm 0.6$	$56.6^{Bd} \pm 1.5$	$59.9^{Ce} \pm 0.5$
a^*	Control	$3.9^{Aa} \pm 0.5$	$4.5^{Ab} \pm 0.8$	$6.6^{Ac} \pm 0.7$	$4.2^{Ab} \pm 1.4$	$5.8^{Ad} \pm 1.2$	$5.3^{Ad} \pm 0.9$	$3.5^{Aa} \pm 0.5$	$3.8^{Aa} \pm 1.5$	$5.3^{Ad} \pm 0.9$
	3 °C 5 min 330 MPa	$2.2^{Ba} \pm 0.1$	$2.8^{Ba} \pm 0.1$	$5.1^{Bb} \pm 0.5$	$4.6^{Ac} \pm 1.0$	$4.3^{Bc} \pm 1.0$	$3.4^{Bd} \pm 0.4$	$3.5^{Ad} \pm 0.1$	$5.9^{Bb} \pm 1.4$	$3.2^{Bd} \pm 0.7$
	25 °C 5 min 220 MPa	$4.8^{Ca} \pm 0.5$	$5.6^{Ab} \pm 0.2$	$5.3^{Bb} \pm 0.6$	$4.0^{Aa} \pm 0.8$	$4.0^{Ba} \pm 0.5$	$3.2^{Bc} \pm 0.3$	$4.0^{Aa} \pm 0.3$	$5.4^{Bb} \pm 0.9$	$4.7^{Ca} \pm 0.5$
b^*	Control	$9.9^{Aa} \pm 1.0$	$10.8^{Aa} \pm 1.2$	$10.6^{Aa} \pm 0.9$	$10.9^{Aa} \pm 1.5$	$10.3^{Aa} \pm 1.3$	$13.0^{Ab} \pm 1.5$	$11.4^{Ac} \pm 0.9$	$14.5^{Ad} \pm 1.3$	$9.4^{Aa} \pm 1.3$
	3 °C 5 min 330 MPa	$9.6^{Aa} \pm 1.1$	$10.6^{Aa} \pm 1.2$	$10.2^{Aa} \pm 0.6$	$13.6^{Bb} \pm 0.9$	$10.4^{Aa} \pm 1.1$	$10.7^{Ba} \pm 1.4$	$11.1^{Ac} \pm 0.7$	$14.0^{Ab} \pm 1.3$	$8.3^{Ad} \pm 0.9$
	25 °C 5 min 220 MPa	$11.9^{Ba} \pm 1.2$	$12.2^{Ba} \pm 0.9$	$9.84^{Ab} \pm 1.1$	$11.7^{Aa} \pm 1.2$	$10.0^{Aa} \pm 1.3$	$10.3^{Ba} \pm 0.5$	$11.3^{Aa} \pm 0.9$	$11.5^{Ba} \pm 1.1$	$13.0^{Bc} \pm 0.4$
ΔE	Control	$1.2^{Aa} \pm 0.9$	$1.6^{Aa} \pm 0.6$	$2.0^{Ab} \pm 0.5$	$2.3^{Ab} \pm 0.5$	$2.0^{Ab} \pm 0.5$	$1.9^{Aa} \pm 0.6$	$1.3^{Aa} \pm 0.2$	$2.0^{Ab} \pm 0.7$	$1.5^{Aa} \pm 0.5$
	3 °C 5 min 330 MPa	$2.8^{Ba} \pm 1.2$	$3.0^{Ba} \pm 0.8$	$2.1^{Aa} \pm 0.5$	$3.8^{Bb} \pm 0.7$	$3.0^{Ba} \pm 0.8$	$3.7^{Bb} \pm 0.5$	$2.3^{Ba} \pm 0.4$	$5.6^{Bc} \pm 0.7$	$11.1^{Bd} \pm 0.6$
	25 °C 5 min 220 MPa	$2.1^{Ba} \pm 0.3$	$2.7^{Ba} \pm 0.6$	$3.9^{Bb} \pm 0.4$	$2.3^{Aa} \pm 0.6$	$2.7^{Aa} \pm 0.6$	$4.0^{Bb} \pm 0.7$	$2.2^{Ba} \pm 0.5$	$7.0^{Cc} \pm 0.8$	$7.3^{Cc} \pm 0.6$

Different letters ($^{A, B, C}$) in the same column indicate significant differences ($p<0.05$).
Different letters ($^{a, b, c}$) in the same line indicate significant differences ($p<0.05$).
[a] All values are the mean ± standard deviation ($n=3$).

Table 5
Changes of pH, TVB-N, TMA and TBA values of the unpressurized and pressurized red mullet stored at 4 °C.[a]

Storage days		1	3	5	7	9	11	13	15	17
pH	Control	$6.4^{Aa}\pm0.1$	$6.6^{Aa}\pm0.1$	$6.6^{Aa}\pm0.0$	$6.7^{Aa}\pm0.1$	$6.7^{Aa}\pm0.1$	$6.5^{Aa}\pm0.1$	$7.1^{Ab}\pm0.1$	$6.0^{Aa}\pm0.1$	$6.5^{Aa}\pm0.2$
	3 °C 5 min 330 MPa	$5.9^{Ba}\pm0.0$	$6.2^{Ba}\pm0.0$	$6.3^{Ba}\pm0.0$	$6.7^{Ab}\pm0.0$	$6.6^{Ab}\pm0.1$	$6.3^{Aa}\pm0.0$	$6.8^{Ab}\pm0.0$	$6.1^{Aa}\pm0.3$	$7.3^{Bc}\pm0.3$
	25 °C 5 min 220 MPa	$6.2^{Aa}\pm0.3$	$6.4^{Aa}\pm0.1$	$6.5^{Aa}\pm0.0$	$6.7^{Aa}\pm0.0$	$6.5^{Aa}\pm0.0$	$6.6^{Aa}\pm0.0$	$7.0^{Ab}\pm0.3$	$6.1^{Aa}\pm0.0$	$6.7^{Aa}\pm0.1$
TVB-N (mg/100 g)	Control	$22.8^{Aa}\pm0.3$	$23.7^{Aa}\pm0.4$	$33.3^{Ab}\pm0.6$	$47.3^{Ac}\pm0.7$	$48.5^{Ac}\pm0.3$	$46.7^{Ac}\pm0.1$	$75.2^{Ad}\pm0.0$	$84.4^{Ae}\pm0.6$	$91.1^{Af}\pm0.3$
	3 °C 5 min 330 MPa	$13.8^{Ba}\pm0.2$	$14.9^{Ba}\pm0.2$	$27.6^{Bb}\pm0.8$	$37.7^{Bc}\pm0.3$	$46.9^{Bd}\pm0.5$	$51.3^{Be}\pm0.8$	$83.8^{Bf}\pm0.3$	$56.3^{Bg}\pm0.1$	$51.2^{Be}\pm0.8$
	25 °C 5 min 220 MPa	$19.9^{Ca}\pm0.3$	$20.2^{Ca}\pm0.1$	$34.3^{Ab}\pm0.4$	$41.9^{Cc}\pm0.7$	$51.3^{Ad}\pm0.8$	$48.2^{Cc}\pm0.1$	$71.3^{Ce}\pm0.4$	$67.9^{Cf}\pm0.6$	$56.8^{Cd}\pm0.8$
TMA-N (mg/100 g)	Control	$2.8^{Aa}\pm0.0$	$3.0^{Aa}\pm0.0$	$5.2^{Ab}\pm0.0$	$7.5^{Ac}\pm0.1$	$5.7^{Ab}\pm0.0$	$6.3^{Ad}\pm0.0$	$10.2^{Ae}\pm0.0$	$11.7^{Af}\pm0.0$	$8.9^{Ag}\pm0.1$
	3 °C 5 min 330 MPa	$0.8^{Ba}\pm0.2$	$0.9^{Ba}\pm0.0$	$3.8^{Bb}\pm0.0$	$6.4^{Bc}\pm0.0$	$6.9^{Bc}\pm0.0$	$7.3^{Bd}\pm0.0$	$10.0^{Ae}\pm0.0$	$11.1^{Af}\pm0.1$	$9.5^{Bg}\pm0.0$
	25 °C 5 min 220 MPa	$1.9^{Ca}\pm0.9$	$2.1^{Ca}\pm0.0$	$4.6^{Cb}\pm0.0$	$5.8^{Cc}\pm0.0$	$6.9^{Bd}\pm0.1$	$7.0^{Bd}\pm0.0$	$11.7^{Ce}\pm0.0$	$10.7^{Bf}\pm0.1$	$9.7^{Bg}\pm0.1$
TBA (mg MDA/kg)	Control	$0.7^{Aa}\pm0.0$	$0.8^{Ab}\pm0.0$	$1.0^{Ac}\pm0.0$	$1.1^{Ad}\pm0.0$	$1.3^{Ae}\pm0.0$	$0.8^{Ab}\pm0.0$	$1.4^{Af}\pm0.0$	$1.7^{Ag}\pm0.1$	$1.1^{Ad}\pm0.0$
	3 °C 5 min 330 MPa	$0.5^{Ba}\pm0.0$	$0.6^{Bb}\pm0.0$	$0.9^{Bc}\pm0.0$	$0.8^{Bd}\pm0.0$	$0.9^{Bc}\pm0.0$	$0.8^{Ad}\pm0.0$	$0.8^{Bd}\pm0.0$	$1.0^{Be}\pm0.0$	$1.2^{Bf}\pm0.0$
	25 °C 5 min 220 MPa	$0.5^{Ba}\pm0.0$	$0.6^{Ba}\pm0.0$	$0.7^{Cb}\pm0.0$	$1.0^{Ac}\pm0.0$	$1.0^{Cc}\pm0.0$	$1.1^{Bd}\pm0.0$	$1.0^{Cc}\pm0.0$	$0.9^{Be}\pm0.0$	$0.8^{Cf}\pm0.1$

Different letters ($^{A, B, C}$) in the same column indicate significant differences ($p<0.05$).
Different letters ($^{a, b, c}$) in the same line indicate significant differences ($p<0.05$).
[a] All values are the mean ± standard deviation ($n=3$).

12.23 and 19.49 reported in our previous work for red mullet and gold band goatfish (Özyurt et al., 2009) as well as that of 13.18 mg N/100 g reported by Gökoğlu et al. (1998) for sardine. Such small differences in TVB-N values may be related to fish non-protein nitrogen (NPN) content which in turn depends on the type of fish feeding, season of catching, fish size, various environmental factors as well as initial microbiological quality of fish tissue (Schormüller, 1968). TVB-N values increased according to time of storage. TVB-N contents of untreated or HP treated red mullets are shown in Table 5. After 7 days of storage, TVB-N remained higher than the rejection limit (35 mg/100 g) for all samples.

TMA is produced by the decomposition of TMAO caused by bacterial spoilage and enzymatic activity. At the beginning of the storage period, TMA-N values for untreated and HP treated red mullet were determined as 2.8 ± 0.0 and 0.9 ± 0.2–1.9 ± 0.9 mg/100 g. In all samples stored at 4 °C conditions TMAs exceeded the value of 10 mg/100 g considered as the upper acceptability limit for marine fishes (Sikorski, Kolakowska, & Burt, 1990), on 13-storage day.

The TBA index is a measure of malonaldehyde content, one of the degradation products of lipid hydroperoxides, formed during the oxidation process of polyunsaturated fatty acids (Gomes, Silva, Nascimento, & Fukuma, 2003; Guillén and Ruiz, 2004). Lipid oxidation is a significant problem relative to off-flavour and off-odour development in fish muscle which typically contains a high percentage of polyunsaturated fatty acids (Goulas & Kontominas, 2007). As can be seen from the results of the present study (Table 5) there is a trend towards an increase in TBA values up to a certain point during the storage period, followed by either a decrease in these values or a lower increase rate. Given that TBA value is a measure of MDA content, which is not stable for long periods of time (Fernández, Perez-Alvarez, & Fernandez-Lopez, 1997), decrease in TBA values may be caused by interaction between MDA and proteins, amino acids, glycogen etc. resulting in lower amount of free MDA as has been reported previously (Gomes et al., 2003; Guillén & Ruiz, 2004; Goulas & Kontominas, 2007). According to Goulas and Kontominas (2007) TBA values of 1–2 mg MDA/kg of fish flesh are usually regarded as the limit beyond which fish will normally develop an objectionable odour/taste. Untreated samples exceed the value of 1 mg MDA/kg throughout the storage period (after 5 days of storage) while the TBA values of samples HP treated at 330 MPa for 5 min at 3 °C and at 220 MPa for 5 min at 25 °C exceeded this value (1 mg MDA/kg) on day 15 and 7 of storage.

In this study, the limit of acceptability (10^6 cfu/g) in terms of psychrotrophic count (Erkan, 2007) was 11 days for untreated samples stored at 4 °C, 17 days for HP treated samples (at 330 MPa for 5 min at 3 °C), and 15 days for HP treated samples (at 220 MPa for 5 min at 25 °C). The result obtained from sensory evaluation, after HP treatment, showed a longer shelf life when compared with microbiological assessment (Table 6). The limit of acceptability (10^6 cfu/g) (Erkan, 2007) in terms of total mesophilic aerobic count was reached at 17 days for HP treated red mullet (at 330 MPa for 5 min at 3 °C/at 220 MPa for 5 min at 25 °C) and stored at 4 °C, while product shelf life exceeded 15 days for such untreated red mullet samples stored at 4 °C. The effectiveness of HPP for reducing or inactivating microbial growth of seafood has been previously reported, including sea bass (Chéret, Chapleau, Delbarre-Ladrat, Verrez-Bagnis, & De Lamballerie, 2005), oyster (He, Adams, Farkas, & Morrissey, 2002), octopus (Hurtado, Montero, & Borderias, 2001), albacore tuna (Ramirez-Suarez & Morrissey, 2006), mahi mahi and rainbow trout (Yağız et al., 2007).

Based primarily on microbiological and sensory results, HP treatment (at 220 MPa for 5 min at 25 °C/at 330 MPa for 5 min at 3 °C) contributed to a considerable slower ($p<0.05$) process of fish spoilage given that the

Table 6
Changes of microbial counts of unpressurized and pressurized red mullet stored at 4 °C.[a]

Storage days		1	3	5	7	9	11	13	15	17
Psychrotrophic bacteria (log cfu/g)	Control	$3.39^{Aa}\pm0.12$	$4.04^{Ab}\pm0.05$	$4.24^{Ab}\pm0.08$	$4.57^{Ab}\pm0.12$	$5.07^{Ac}\pm0.01$	$6.29^{Ad}\pm0.08$	$6.47^{Ad}\pm0.18$	$6.80^{Ad}\pm0.15$	$7.35^{Ae}\pm0.07$
	3 °C 5 min 330 MPa	$<3^{Ba}\pm0.00$	$3.50^{Ab}\pm0.71$	$4.09^{Ac}\pm0.13$	$4.35^{Ac}\pm0.07$	$4.89^{Bc}\pm0.01$	$5.02^{Bd}\pm0.03$	$5.30^{Bd}\pm0.14$	$5.70^{Bd}\pm0.14$	$6.35^{Be}\pm0.07$
	25 °C 5 min 220 MPa	$<3^{Ba}\pm0.00$	$3.55^{Ab}\pm0.49$	$4.17^{Ac}\pm0.02$	$4.47^{Ac}\pm0.10$	$4.96^{Bc}\pm0.01$	$5.11^{Bd}\pm0.04$	$5.60^{Bd}\pm0.00$	$6.10^{Ae}\pm0.14$	$6.55^{Be}\pm0.21$
Mesophilic aerobic bacteria (log cfu/g)	Control	$3.77^{Aa}\pm0.11$	$4.55^{Ab}\pm0.03$	$4.55^{Ab}\pm0.07$	$4.51^{Ab}\pm0.04$	$4.57^{Ab}\pm0.04$	$4.62^{Ab}\pm0.19$	$5.97^{Ac}\pm0.02$	$6.97^{Ad}\pm0.07$	$8.16^{Ae}\pm0.06$
	3 °C 5 min 330 MPa	$<3^{Ba}\pm0.00$	$<3^{Ba}\pm0.00$	$4.26^{Ab}\pm0.21$	$4.33^{Ab}\pm0.10$	$4.24^{Ab}\pm0.08$	$4.35^{Ab}\pm0.07$	$4.52^{Bb}\pm0.03$	$5.69^{Bc}\pm0.00$	$6.25^{Bd}\pm0.07$
	25 °C 5 min 220 MPa	$<3^{Ba}\pm0.00$	$3.15^{Cb}\pm0.21$	$4.17^{Ac}\pm0.02$	$4.39^{Ac}\pm0.13$	$4.33^{Ac}\pm0.10$	$4.44^{Ac}\pm0.06$	$4.63^{Bc}\pm0.04$	$5.70^{Bd}\pm0.07$	$6.47^{Be}\pm0.00$

Different letters ($^{A, B, C}$) in the same column indicate significant differences ($p<0.05$).
Different letters ($^{a, b, c}$) in the same line indicate significant differences ($p<0.05$).
[a] All values are the mean ± standard deviation ($n=3$).

fishes remained acceptable up to ca. 14–15 days of storage corresponding to a ca. 3–4 days shelf-life extension as compared with control samples.

Acknowledgment

This work was supported by the Research Fund of Istanbul University with project T-1392 and the TUBİTAK project 108O668.

References

Amanatidou, A., Schlüter, O., Lemkau, K., Gorris, L. G. M., Smid, E. J., & Knorr, D. (2000). Effect of combined application of high pressure treatment and modified atmospheres on the shelf life of fresh Atlantic salmon. *Innovative Food Science & Emerging Technologies*, *1*, 87—98.

Angsupanich, K., & Ledward, D. A. (1998). High pressure treatment effects on cod (*Gadus morhua*) muscle. *Food Chemistry*, *63*(1), 39—50.

Antonacopoulos, N., & Vyncke, W. (1989). Determination of volatile basic nitrogen in fish. *Zeitschrift für Lebensmittel-Untersuchung und Forschung*, *189*, 309—316.

AOAC 1998a. Official Method 955.04, Nitrogen (Total) in Seafood. Fish and Other Marine Products, James M. Hungerford, Chapter Editor. Hungerford, J.M. in *Official Methods of Analysis of AOAC International*, Editor. Cunniff, P. AOAC International: Gaithersburg, Maryland, Chapter 35, p.6.

AOAC 1998b. Official Method 948.15 Fat (crude) in Seafood. Acid Hydrolysis Method, Fish and Other Marine Products, In: Hungerford JM, Chapter Editor. in *Official Methods of Analysis of AOAC International*; Cunniff, P. AOAC International: Gaithersburg, Maryland, Chapter 35; 6.

AOAC 1998c. Official Method 938.08, Ash of Seafood. Fish and Other Marine Products, Hungerford, J.M. Chapter Editor. in *Official Methods of Analysis of AOAC International*, Cunniff, P. Eds. AOAC International: Gaithersburg, Maryland, Chapter 35, p.6.

AOAC 1998d. AOAC Official Method 971.14, Trimethylamine Nitrogen in Seafood Colorimetric Method. In: Hungerford JM Chapter Editor. *Fish and Other Marine Products.* In: Cunniff, P. Eds. Official Methods of Analysis of AOAC International, Chapter 35, p 7.

Ashie, I. N. A., Smith, J. P., & Simpson, B. K. (1996). Spoilage and shelf-life extension of fresh fish and shellfish. *Critical Reviews in Food Science and Nutrition*, *36*(1–2), 87—121.

Baumgart, J., 1986, Lebensmittel tierischer Herkunft, Feinkosterzeugnisse, gefrorene, tiefgefrorene und getrocknete lebensmittel, Fertiggerichte, hitzekonservierte Lebensmittel, Speiseeis, Zucker, Kakao, Zuckerwaren, Rohmassen. *Mikrobiologische Untersuchung von Lebensmitteln.* Edt: Baumgart, J. und unter Firnhaber, J. Gottfried Spicher. p. 207, Behr's Verlag ISBN: 3-922528-91-0 Hamburg.

Büyükcan, M., Bozoğlu, F., & Alpas, H. (2009). Preservation and shelf-life extension of shrimps and clams by high hydrostatic pressure. *International Journal of Food Science and Technology*, *44*, 1495—1502.

Chéret, R., Chapleau, N., Delbarre-Ladrat, C., Verrez-Bagnis, V., & De Lamballerie, M. (2005). Effects of high pressure on texture and microstructure of sea bass (*Dicentrarchus labrax* L.) fillets. *Journal of Food Science*, *70*(8), E477—E483.

Chevalier, D., Le Bail, A., & Ghoul, M. (2001). Effects of high pressure treatment (100–200 MPa) at low temperature on turbot (*Scophthalmus maximus*) muscle. *Food Research International*, *34*, 425—429.

Cruz-Romero, M., Smiddy, M., Hill, C., Kerr, J. P., & Kelly, A. L. (2004). Effects of high pressure treatment on physicochemical characteristics of fresh oysters (*Crassostrea gigas*). *Innovative Food Science and Emerging Technologies*, *5*, 161—169.

Cruz-Romero, M., Kelly, A. L., & Kerry, J. P. (2008). Effects of high-pressure treatment on the microflora of oysters (*Crassostrea gigas*) during chilled storage. *Innovative Food Science and Emerging Technologies*, *9*, 441—447.

Cruz-Romero, M., Kelly, A. L. And, & Kerry, J. P. (2008). Influence of packaging strategy on microbiological and biochemical changes in high-pressure-treated oysters (*Crassostrea gigas*). *Journal of the Science of Food and Agriculture*, *88*, 2713—2723.

Debevere, J., & Boskou, G. (1996). Effect of modified atmosphere packaging on the TVB/TMA-producing microflora of cod fillets. *International Journal of Food Microbiology*, *31*, 221—229.

Erkan, N. (2007). Freshness and quality of aquacultured sea bass (*Dicentrarchus labrax*) and sea bream (*Sparus aurata*) stored in ice. *Archiv für Lebensmittelhygiene*, *58*(3), 98—106.

Erkan, N., & Özden, Ö. (2008). Quality assessment of whole and gutted sardine (*Sardine pilchardus*) stored in ice. *International Journal of Food Science and Technology*, *43*(9), 1549—1559.

Erkan, N., & Üretener, G. (2010). The effect of high hydrostatic pressure on the microbiological, chemical and sensory quality of fresh gilthead sea bream (*Sparus aurata*). *European Food Research and Technology*, *230*, 533—542.

Fernández, J., Perez-Alvarez, J. A., & Fernandez-Lopez, J. A. (1997). Thiobarbituric acid test for monitoring lipidoxidation in meat. *Food Chemistry*, *59*, 345—353.

Gennari, M., Tomaselli, S., & Cotrona, V. (1999). The micro flora of fresh and spoiled sardines (*Sardina pilchardus*) caught in Adriatic (Mediterranean) Sea and stored in ice. *Food Microbiology*, *16*, 15—28.

Gerdes, D. L., & Santos Valdez, C. (1991). Modified atmosphere packaging of commercial Pacific red snapper (*Sebastes entomelas, Sebastes flavidus* or *Sebastes godei*). *Lebensmittel-Wissenschaft und Technologie*, *24*, 256—258.

Gomes, H. A., Silva, E. N., Nascimento, M. R. L., & Fukuma, H. T. (2003). Evaluation of the 2-thiobarbituric acid method for the measurement of lipid oxidation in mechanically deboned gamma irradiated chicken meat. *Food Chemistry*, *80*, 433—437.

Goulas, A. E., & Kontominas, M. G. (2007). Effect of modified atmosphere packaging and vacuum packaging on the shelf-life of refrigerated chub mackerel (*Scomber japonicus*): Biochemical and sensory attributes. *European Food Research and Technology*, *224*, 545—553.

Gökoğlu, N., Özden, Ö., & Erkan, N. (1998). Physical, chemical and sensory analyses of freshly harvested sardines (*Sardina pilchardus*) stored at 4 °C. *Journal of Aquatic Food Product Technology*, *7*, 5—15.

Gram, L., & Huss, H. H. (1996). Microbiological spoilage of fish and fish products. *International Journal of Food Microbiology*, *33*(1), 121—137.

Guillén, M. D., & Ruiz, A. (2004). Study of the oxidative stability of salted and unsalted salmon fillets by ^{1}H nuclear magnetic resonance. *Food Chemistry*, *86*(2), 297—304.

He, H., Adams, R. M., Farkas, D. F., & Morrissey, M. T. (2002). Use of high-pressure processing for oyster shucking and shelf-life extension. *Journal of Food Science*, *67*(2), 640—645.

Hurtado, J. L., Montero, P., & Borderias, J. (2001). Chilled storage of pressurized octopus (*Octopus vulgaris*) muscle. *Journal of Food Science*, *66*(3), 400—406.

Huss, H.H., 1988. Fresh fish quality and quality changes, FAO Fisheries Series, No. 29. Rome: FAO.

Ludorff, W., & Meyer, V. (1973). *Fische und fischerzeugnisse.* Hamburg, Berlin: Paul Parey Verlag.

Mattissek, R., Schnepel, M.F., Steiner, G., 1992. Lebensmittelanalytik, Grundzüge. Methoden. Anwendungen. p.440, Zweite, korrigierte Auflage. Springer Berlin Heidelberg New York, ISBN: 3-540-54684-7.

Matser, A. M., Stegeman, D., Kals, J., & Bartels, P. V. (2000). Effects of high pressure on colour and texture of fish. *High Pressure Research*, *19*(1–6), 499—505.

Ohshima, T., Ushio, H. And, & Koizumi, C. (1993). High pressure processing of fish and fish products. *Trends in Food Science and Technology*, *4*, 370—375.

Özyurt, G., Kuley, E., Özkütük, S., & Özoğul, F. (2009). Sensory, microbiological and chemical assessment of the freshness of red mullet (*Mullus barbatus*) and goldband goatfish (*Upeneus moluccensis*) during storage in ice. *Food Chemistry*, *114*, 505—510.

Ramirez-Suarez, J. C., & Morrissey, M. T. (2006). Effect of high pressure processing (HPP) on shelf life of albacore tuna (*Thunnus alalunga*) minced muscle. *Innovative Food Science and Emerging Technologies*, *7*(1–2), 19—27.

Reza, Md. S., Bapary, M. A. J., Ahasan, C. T., Islam, Md. N., & Kamal, Md. (2009). Shelf life of several marine fish species of Bangladesh during ice storage. *International Journal of Food Science and Technology*, *44*, 1485—1494.

Sasi, M., Jeyasekaran, G., Shanmugam, S. A., & Jeya Shakila, R. (2003). Evaluation of the quality of seer fish (*Scomberomorus commersonii*) stored in dry ice (solid carbon dioxide). *Journal of Aquatic Food Product Technology*, *12*(2), 61—72.

Schormüller, J. (1968). *Handbuch der lebensmittelchemie (Band III / 2).* Berlin, Heidelberg, New York: Springer Verlag.

Sequeria-Munoz, A., Chevalier, D., Lebabile, A., Ramaswamy, S. H., & Simpson, B. K. (2006). Physicochemical changes induced in carp (*Cyprinus carpio*) fillets by high pressure processing at low temperature. *Innovative Food Science and Emerging Technologies*, *7*, 13—18.

Sikorski, Z. E., Kolakowska, A., & Burt, J. R. (1990). *Postharvest biochemical and microbial changes: Seafood: Resources nutritional composition and preservation.*Boca Raton, Florida: CRC Pres 55–75.

Stamatis, N., & Arkoudelos, J. (2007). Quality assessment of *Scomber colias japonicus* under modified atmosphere and vacuum packaging. *Food Control*, *18*, 292—300.

Sümbüloğlu, K., Sümbüloğlu, V., 2002. *Biyoistatistik*, Hatipoğlu Basım ve Yayım San. Tic. Ltd. Sti., Ankara, 975-7527-12-2.

Yağız, Y., Kristinsson, H. G., Balaban, M. O., & Marshall, M. R. (2007). Effect of high pressure treatment on the quality of rainbow trout (*Oncorhynchus mykiss*) and mahi mahi (*Coryphaena hippurus*). *Journal of Food Science*, *72*(9), C509—C515.

Yağız, Y., Kristinsson, H. G., Balaban, M.Ö., Welt, B. A., Ralat, M., & Marshall, M. R. (2009). Effect of high pressure processing and cooking treatment on the quality of Atlantic salmon. *Food Chemistry*, *116*, 828—835.

Zare, Z., 2004. High pressure processing of fresh tuna fish and its effects on shelf life. A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfilment of the degree of Master of Science.

Innovative Food Science and Emerging Technologies xxx (2011) xxx–xxx

Contents lists available at ScienceDirect

Innovative Food Science and Emerging Technologies

journal homepage: www.elsevier.com/locate/ifset

The effect of different high pressure conditions on the quality and shelf life of cold smoked fish

Nuray Erkan [a,*], Gonca Üretener [b], Hami Alpas [c], Arif Selçuk [d], Özkan Özden [a], Sencer Buzrul [e]

[a] Istanbul University, Faculty of Fisheries, Department of the Seafood Processing and Quality Control, Ordu Cad. No. 200 34470, Istanbul, Turkey
[b] Istanbul University, Institute of Science, Department of Fisheries and Seafood Processing, Bozdoğan Kemeri cad. No. 6 İşitme Engelliler Okulu Yanı Vezneciler/Istanbul, Turkey
[c] Food Engineering Department, Middle East Technical University, 06531, Ankara, Turkey
[d] TÜBİTAK Marmara Research Center, Food Institute, Gebze/Kocaeli, Turkey
[e] Tütün ve Alkol Piyasası Düzenleme Kurumu (TAPDK), 06520, Ankara, Turkey

A R T I C L E I N F O

Article history:
Received 12 April 2010
Accepted 9 December 2010
Available online xxxx

Editor Proof Receive Date 07 January 2011

Keywords:
Cold smoked salmon
High pressure treatment
Quality
Shelf life

A B S T R A C T

Cold smoked salmon were HP treated at 220, 250 and 330 MPa, at 3, 7, 15 and 25 °C for 5 and 10 min. The influences of such treatments on some quality parameters (the changes of colour, TBA and TMA values) were studied. These parameters were determined for cold smoked salmon suitable combinations (at 220–250 MPa, 3 °C for 5 min, at 330 MPa, 15 °C for 5 min and at 250 MPa, 25 °C for 10 min). In the second stage the shelf life of cold smoked salmon HP treated at 250 MPa, 3 °C for 5 min and at 250 MPa, 25 °C for 10 min and stored at 2 °C was investigated by measurement of sensory, chemical and microbiological analyses. Based on the sensory and microbiological results, the control samples were acceptable only up to 6 weeks, compared to 8 weeks in HP treatment cold smoked salmon samples, extending the shelf-life by 2 weeks.

Industrial relevance: Little information exists on the effects on physical and biochemical characteristics and shelf life of HP-treated cold smoked samples, compared to other preserved methods. This paper illustrates the changes induced in cold smoked salmon flesh by pressurization at different conditions. HP treatment significantly changed the sensory, chemical and microbiological properties of cold smoked salmons, and in combination with adequate chilled storage, can improve the shelf-life and safety of cold smoked salmons.

1. Introduction

Smoking is one of the oldest means of preserving fish and meat. The preservative effect is due to the presence of some antimicrobial compounds in smoke such as phenols and formaldehyde (Tülsner, 1994). Cold-smoked fish is of considerable economic importance worldwide particularly in Europe. This foodstuff is produced by a light salting and smoking process and is typically consumed as ready-to-eat with no heat treatment. Information on quality and shelf life of cold smoked fish stored in refrigerator is available in literature. Cold smoked fish, usually stored at chilled temperature, is very sensitive to deterioration and, based on sensory evaluation, has a limited shelf life often 2–4 weeks, though it may be up to 6 weeks (Rorvik, Yndestad, & Skjerve, 1991; Kolsarıcı & Özkaya, 1998; Dondero, Cisternas, Carvajal, & Simpson, 2004).

In recent years, studies have focussed on new preservation methods aimed at extending the shelf-life and improving the quality of smoked fish products. High pressure (HP) technology is relatively new to food industry and is more and more considered as an alternative to traditional preservation methods like heat processing. Inactivation of bacteria, spores, and virus has been demonstrated (Thakur & Nelson, 1998; Yuste, Capellas, Pla, Fung, & Mor-Mur, 2001). However, in complex matrices like food the desired effect of e.g. microbial inactivation may also produce physical and biochemical changes which may affect the product properties in a negative manner. Undesirable physicochemical changes can be monitored by colour, texture and thiobarbituric acid analysis (Erkan & Üretener, 2010; Erkan, Üretener, & Alpas, 2010). The suitable selection of the processing parameters temperature, time and pressure can ensure that the processing goal is reached without extensive detrimental effects (Heinz & Bukow, 2010). High pressures have been employed of late to preserve various smoked fish species (Lakshmanan, Miskin, & Piggot, 2005; Gómez-Estace, Gómez-Guillén, & Montero, 2007). Nevertheless, application of high pressures to smoked fish is a recent development, and as a consequence the literature is limited.

This study was conducted in two stages. First, the effects of a variety of treatments (different pressure levels, hold times and temperature combinations) on cold-smoked salmon were evaluated in order to determine the conditions which give optimum quality attributes in terms of colour, trimethylamine nitrogen (TMA-N) and thiobarbituric acid (TBA) values, relative to controls. Two combinations were selected for further

* Corresponding author. Istanbul University, Faculty of Fisheries, Department of Seafood Processing and Quality Control, Ordu Cad. No. 200 34470 Laleli/Istanbul, Turkey. Tel.: +90 212 455 57 00/16415; fax: +90 212 455 58 61.
E-mail address: nurerkan@istanbul.edu.tr (N. Erkan).

1466-8564/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ifset.2010.12.004

study. Quality attributes, based on sensory, chemical and microbiological changes, were evaluated during storage of the salmon for 8 weeks at 2 °C.

2. Materials and methods

2.1. Samples

Cold smoked salmon fillets were purchased from Alarko-Leröy, Company in Kocaeli (Turkey). Samples in ice boxes were transported to the laboratory within 6 h. This study took place in two stages. Three kilograms of samples (15 fillets) was used for the experiment in the first stage. The fish were divided into portions of equal weight (15 g). The samples were covered with flexible plastic films to avoid direct contact between the samples and pressure transmitting fluid. Then they were pressurized at 220, 250 and 330 MPa at 3, 7, 15 and 25 °C for 5 and 10 min. Colour (L*, a* and b* value) was measured in all samples. Samples were frozen to −30 °C until use for TMA-N and TBA value measurement. Colour and TBA analysis results that were considered collectively (control sample close to the value L*, a*, b* and control sample close to the value or lower TBA values based) for cold smoked salmon HP application for the best combination were determined.

Two batches were prepared to study the behaviour of both the pressurized and the unpressurized cold smoked salmon during chilled storage (second experiment). Six kilograms of samples (30 fillets) was used for the second experiment. Samples was pressurized at 250 MPa, 3 °C, for 5 min and at 250 MPa, 25 °C for 10 min and then stored at 2 °C, and the other batch (No HP) was stored directly at 2 °C without undergoing high pressure treatment. After treatment, samples were stored for 8 weeks at 2 °C. Samples were placed into oxygen permeable bags for the storage study.

2.2. HHP treatment

HHP treatments were performed in a designed and constructed laboratory-scale unit (capacity: 30 cm^3, maximum pressure: 500 MPa). Water was used as the pressure-transmitting medium. The equipment consists of a pressure chamber of cylindrical design, two end closures, a means for restraining the end closures, a pressure pump and a hydraulic unit to generate high pressure for system compression, and also a temperature control device. The pressure vessel was made of hot galvanized carbon steel and piston was hard chrome-plated and polished to mirror finish (steel-type heat-treated special K) which was processed into the required sizes at the Electrical and Electronic Engineering Department of Middle East Technical University (Ankara, Turkey). The liquid was heated prior to pressurization to the desired temperature by an electrical heating system surrounding the chamber. Time to reach the desired pressure and also for decomposition was approximately 5–10 s for the system.

2.3. Analyses

2.3.1. Physical analyses

2.3.1.1. Colour analyses. The colour of the fish samples was determined with the help of a Konica Minolta chromo meter (model CR 400/410; Minolta, Osaka, Japan). L^* (brightness), a^* ($+a$, red; $-a$, green) and b^* ($+b$, yellow; $-b$, blue) values were measured. The colourimeter was calibrated using white references (CR-A44). The colour was measured on homogenates prepared from ten fish fillets. The homogenate was placed in plastic petri dishes and the colour measurement was repeated 10 times. Averages and standard deviations of L^*, a^* and b^* values were calculated as the total colour differences. The total colour difference (ΔE), as calculated below, was also used for evaluation, $\Delta E = (\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{1/2}$ where ΔL^*, Δa^* and Δb^* are the differences of the L^*, a^* and b^* values between the treated samples and control (Gerdes & Santos Valdez, 1991).

2.3.2. Chemical analysis

2.3.2.1. Measurement of pH. One gram of each sample was blended with 10 mL distilled water. The pH of the fish homogenate was measured using a digital pH meter Hanna pH 211 Microprocessor pH meter (HANNA Instruments, Michigan, USA), standardized at pH 4.0 and 7.0 (Erkan, 2007).

2.3.2.2. Measurement of thiobarbituric acid value (TBA). The thiobarbituric acid value (TBA) was determined colourimetric by the method of Erkan and Özden (2008). A portion (500 mg) of sample was weighed into a 50 mL volumetric flask. An aliquot (45 mL) of a 5% (w/v) solution of TCA and 100 μL butylated hydroxytoluene was added and in an Ultra-Turrax, homogenised at high speed for 2 min. The mixture was filtered through a Whatman No. 1 filter paper. A portion (5.0 mL) of the mixture that was pipetted into a dry stoppered test tube 5 mL of TBA reagent (0.02 M of the solution of 2-thiobarbituric acid in 90% acetic acid) was added. The test tubes were stoppered, vortexed and placed in a water bath at 80 °C for 30 min, then cooled. Absorbance was measured at 532 nm against water blank. The concentration of MDA was calculated from a standard curve using 1,1,3,3-tetraethoxy-propane (TEP) as the standard compound. TBA values were expressed as mg of malondialdehyde (MDA)/kg of sample.

2.3.2.3. Measurement of trimethylamine nitrogen (TMA-N). TMA-N was determined by the method of AOAC (1998). Homogenised samples (10 g) were weighed, blended with 90 mL of 7.5% trichloroacetic acid (TCA) solution and filtrated. Blended solution was fixed with formaldehyde (20%). Four millilitres of extract was transferred into test tubes and 1 mL formaldehyde, 10 mL anhydrous toluene and 3 mL KOH (20 %) solutions were added. The tubes were shaken and 5 mL toluene layer was pipetted. Five millilitres of picric acid working solution (0.02%) was added. The contents were mixed and transferred to a spectrophotometric cell. Absorbance at 410 nm against the blank was measured. The concentration of TMA-N was calculated from a standard curve using trimethylamine hydrochloride as the standard compound. Results of TMA-N were expressed as mg per 100 g of muscle.

2.3.2.4. Measurement of total volatile basic nitrogen (TVB-N). Total volatile basic nitrogen (mg TVB-N/100 g) was determined according to the method of Antonacopoulos and Vyncke (1989). For total volatile basic nitrogen (TVB-N), fish muscle (10 g) was homogenised with 6% perchloric acid (90 mL) for 1 min in an Ultra-Turrax. The homogenates were filtered through a filter paper (Whatman no 1) and filtrates alkalized by NaOH (20%) before distillation duplicate filtrates were distilled in a Velp Marka (Model UDK 140, Milan, Italy)

Table 1
Sensory scale.

Attributes/quality	7–9 = very good	6–6.9 = good quality	5–5.9 = acceptable quality	4.9–1.0 = spoiled
Appearance	Pink, translucent	Pink, moist, translucent	Pale pink or orange	Many pale pink or orange
Odour	Pungent smoky, salty	Smoky salty	Metallic	Rancid
Taste	Pungent smoky, salty	Smoky salty	Metallic	Rancid
Texture	Soft	Mild soft	Neutral	Loose

Please cite this article as: Erkan, N., et al., The effect of different high pressure conditions on the quality and shelf life of cold smoked fish, *Innovative Food Science and Emerging Technologies* (2011), doi:10.1016/j.ifset.2010.12.004

Table 2
Colour changes of untreated and HP-treated cold smoked salmon.

Temperature/time		3 °C/5 min	3 °C/10 min	7 °C/5 min	7 °C/10 min	15 °C/5 min	15 °C/10 min	25 °C/5 min	25 °C/10 min
L*	Untreated	54.1 ± 2.1^{Aa}	54.1 ± 2.1^{Aa}	54.1 ± 2.1^{Aa}	54.1 ± 2.1^{Aa}	54.1 ± 2.1^{Aa}	54.1 ± 2.1^{Aa}	54.1 ± 2.1^{Aa}	54.1 ± 2.1^{Aa}
	220 MPa	53.5 ± 1.9^{Aa}	56.3 ± 2.0^{Aa}	52.6 ± 1.9^{Aa}	53.1 ± 3.3^{Aa}	49.7 ± 1.8^{Ba}	48.8 ± 1.2^{Bb}	47.8 ± 1.3^{Bb}	50.2 ± 3.2^{Aa}
	250 MPa	52.0 ± 1.7^{Aa}	52.1 ± 1.4^{Aa}	53.8 ± 2.1^{Aa}	54.2 ± 0.5^{Aa}	49.6 ± 4.2^{Aa}	52.0 ± 3.9^{Aa}	55.3 ± 1.9^{Aa}	54.6 ± 2.1^{Aa}
	330 MPa	58.4 ± 2.5^{Aa}	55.8 ± 1.0^{Aa}	55.5 ± 1.4^{Aa}	56.7 ± 1.1^{Aa}	55.6 ± 0.6^{Aa}	54.2 ± 1.9^{Aa}	56.2 ± 1.5^{Aa}	55.7 ± 2.2^{Aa}
a*	Untreated	20.7 ± 1.9^{Aa}	20.7 ± 1.9^{Aa}	20.7 ± 1.9^{Aa}	20.7 ± 1.9^{Aa}	20.7 ± 1.9^{Aa}	20.7 ± 1.9^{Aa}	20.7 ± 1.9^{Aa}	20.7 ± 1.9^{Aa}
	220 MPa	21.1 ± 1.1^{Aa}	20.2 ± 3.0^{Aa}	22.5 ± 1.2^{Aa}	22.3 ± 1.8^{Aa}	18.9 ± 2.8^{Ab}	19.9 ± 3.9^{Aa}	20.7 ± 2.7^{Aa}	23.1 ± 1.7^{Aa}
	250 MPa	19.4 ± 2.5^{Aa}	19.3 ± 0.9^{Aa}	20.9 ± 2.6^{Aa}	17.3 ± 2.7^{Aa}	20.0 ± 1.4^{Aa}	19.7 ± 3.1^{Aa}	20.6 ± 2.7^{Aa}	23.0 ± 1.6^{Ab}
	330 MPa	22.4 ± 3.2^{Aa}	19.6 ± 1.1^{Aa}	21.3 ± 0.7^{Aa}	21.2 ± 1.5^{Aa}	21.0 ± 1.8^{Aa}	18.8 ± 1.5^{Aa}	18.8 ± 1.0^{Aa}	19.8 ± 0.4^{Aa}
b*	Untreated	28.5 ± 1.5^{Aa}	28.5 ± 1.5^{Aa}	28.5 ± 1.5^{Aa}	28.5 ± 1.5^{Aa}	28.5 ± 1.5^{Aa}	28.5 ± 1.5^{Aa}	28.5 ± 1.5^{Aa}	28.5 ± 1.5^{Aa}
	220 MPa	27.7 ± 0.9^{Aa}	31.6 ± 6.6^{Aa}	29.6 ± 2.2^{Aa}	28.8 ± 3.7^{Aa}	26.8 ± 3.0^{Aa}	27.3 ± 2.3^{Aa}	27.5 ± 3.8^{Aa}	28.7 ± 2.3^{Aa}
	250 MPa	27.8 ± 2.1^{Aa}	27.1 ± 1.7^{Aa}	29.4 ± 4.6^{Aa}	25.0 ± 3.8^{Aa}	25.0 ± 2.7^{Aa}	27.1 ± 3.8^{Aa}	27.2 ± 3.4^{Aa}	28.2 ± 2.1^{Aa}
	330 MPa	29.2 ± 3.0^{Aa}	25.7 ± 2.0^{Aa}	28.1 ± 1.1^{Aa}	27.6 ± 2.2^{Aa}	28.9 ± 1.8^{Aa}	23.3 ± 2.3^{Bb}	25.8 ± 1.9^{Aa}	24.9 ± 1.1^{Ba}
ΔE	Untreated	–	–	–	–	–	–	–	–
	220 MPa	2.5 ± 1.1^{Aa}	7.2 ± 4.5^{Ab}	3.9 ± 1.0^{Aa}	5.3 ± 1.6^{Ab}	6.8 ± 0.9^{Ab}	6.9 ± 2.0^{Ab}	7.8 ± 1.8^{Ab}	6.0 ± 1.5^{Ab}
	250 MPa	4.4 ± 0.8^{ABa}	3.5 ± 1.2^{Aa}	5.3 ± 2.0^{Aa}	5.9 ± 3.0^{Aa}	6.4 ± 4.2^{Aa}	6.2 ± 2.0^{Aa}	4.7 ± 1.8^{Aa}	3.9 ± 1.0^{a}
	330 MPa	6.5 ± 2.4^{Ba}	4.1 ± 1.1^{Aa}	2.3 ± 0.9^{Ab}	3.8 ± 1.3^{Ab}	3.0 ± 0.4^{Ab}	6.0 ± 2.2^{Aa}	4.6 ± 1.3^{Aa}	4.6 ± 0.7^{Aa}

All values are the mean ± standard deviation (n = 3). Different letters (^{A,B}) in the same column indicate significant differences (p<0.05). Different letters (^{a,b}) in the same line indicate significant differences (p<0.05).

apparatus. The distillate titrated with 0.01 N HCl. Results of TMA-N were expressed as mg per 100 g of muscle.

2.3.2.5. Measurement of free amino acid. Free amino acid content of untreated and HP-treated samples was determined using the hydrolysis and derivatization technique described by Erkan, Selçuk, and Özden (2010). The amino acids were determined by using HPLC. In this study, it was determined that cold smoked salmon contained lysine (lys), methionine (meth), isoleucine (isoleu), leucine (leu), phenylalanine (phen), valine (val), histidine (his), serine (ser), arginine (arg), cysteine (cys), tyrosine (tyr), alanine (ala), aspartic acid (asp), glutamic acid (glut), glycine (gly) and proline (prol). Amino acids were identified by comparison of their retention time with those of an authentic standard (Pierce, Amino Acid Standard Hydrolyzate, Product No: 20078 20088 20089 1800180 NCI0180, Rockford, IL, USA) and their contents were calculated on a weight basis (mg/100 g).

2.3.3. Sensory analysis

The attributes of cold smoked fish were evaluated by a panel of five experienced judges on each day of sampling. Sensory evaluation was conducted in individual booths under controlled conditions of light, temperature and humidity. Sensory analysis was performed using the scales of Amerina, Pangborn, and Roessler (1965). HP treated and non treated fish slices were assessed on the basis of appearance, odour, taste and texture characteristics using a nine point descriptive scale (Table 1). On the day of each analysis for each parameter, the average scores of panellists were calculated.

2.3.4. Microbiological analyses

Microbiological counts were determined by placing 25 g sample in 225 mL of 0.1% peptone water (Merck, Cat No: 107228), and homogenising it with a stomach (Stomacher, IUL Instrument, Spain). From this dilution, other decimal dilutions were prepared and plated on the appropriate media. Total viable counts (TVC) were determined by the pour plate method, using plate count agar (PCA, Merck, Cat No: 105463). The inoculated plates were incubated at 37 °C for 24–48 h for TVC's and at 7 °C for 10 days for psychrophilic counts (TPC) (Baumgart, 1986). Results are expressed as a logarithm of colony forming units per gram of sample ($\log_{10}$cfu/g).

2.3.5. Statistical analysis

The experiments were repeated twice. The measurements were run in triplicates for each replicate ($n = 2 \times 3$). The results were reported as mean values ± standard deviation. Significant differences between the samples (for sensory, pH, colour, TBA, TVB-N, TMA-N and microbiological analysis) were calculated by Excel XP 2003 by one-way analysis of variance (ANOVA) using a significance level of p<0.05 by Tukey's honestly significant difference test. Calculations for free amino acid made were the mean, standard deviation, coefficients of variation in percent and F-setting the confidence level at 95% test (Sümbüloğlu & Sümbüloğlu, 2002).

3. Results and discussion

Changes in the colour of cold smoked salmon samples are shown in Table 2. The only treatments that gave significantly different (lower) L* values, compared to controls were 220 MPa/15 °C/5 min; 220 MPa/15 °C/10 min and 220 MPa/25 °C/5 min. In the case of a* values, the only treatments which were significantly different were 220 MPa/15 °C/5 min and 250 MPa/25 °C/10 min. In the case of b* values, the only treatments that are significantly different were 330 MPa/15 °C/10 min and 330 MPa/25 °C/10 min. Looking at the delta E (ΔE) scores, the lowest score (least change) was obtained with a treatment of 220 MPa/3 °C/5 min. Overall, the colour values varied

Table 3
TBA and TMA-N content changes of untreated and HP-treated cold smoked salmon.

Temperature/time		3 °C/5 min	3 °C/10 min	7 °C/5 min	7 °C/10 min	15 °C/5 min	15 °C/10 min	25 °C/5 min	25 °C/10 min
TBA	Untreated	3.68 ± 0.22^{Aa}	3.68 ± 0.22^{Aa}	3.68 ± 0.22^{Aa}	3.68 ± 0.22^{Aa}	3.68 ± 0.22^{Aa}	3.68 ± 0.22^{Aa}	3.68 ± 0.22^{Aa}	3.68 ± 0.22^{Aa}
	220 MPa	3.70 ± 0.24^{Aa}	4.43 ± 0.18^{Bb}	4.43 ± 0.39^{Bb}	4.79 ± 0.14^{Bb}	3.87 ± 0.62^{Aa}	3.56 ± 0.32^{Aa}	3.98 ± 0.95^{Ba}	3.96 ± 0.96^{Aa}
	250 MPa	3.47 ± 0.23^{Aa}	4.76 ± 0.36^{Bb}	4.36 ± 0.19^{Bb}	4.82 ± 0.50^{Bb}	3.71 ± 0.16^{Aa}	3.67 ± 0.18^{Ac}	4.19 ± 0.08^{Cd}	3.92 ± 0.87^{Ab}
	330 MPa	4.05 ± 0.33^{Aa}	5.12 ± 0.32^{Bb}	4.60 ± 0.29^{Ba}	4.49 ± 0.44^{Ba}	4.11 ± 0.55^{Aa}	3.86 ± 0.16^{Aa}	4.10 ± 0.09^{Ca}	3.99 ± 0.90^{Aa}
TMA-N	Untreated	0.69 ± 0.07^{Aa}	0.69 ± 0.07^{Aa}	0.69 ± 0.07^{Aa}	0.69 ± 0.07^{Aa}	0.69 ± 0.07^{Aa}	0.69 ± 0.07^{Aa}	0.69 ± 0.07^{Aa}	0.69 ± 0.07^{Aa}
	220 MPa	0.85 ± 0.08^{Ba}	0.87 ± 0.08^{Ba}	0.30 ± 0.06^{Bb}	0.68 ± 0.31^{Aa}	0.84 ± 0.11^{Aa}	0.76 ± 0.05^{Aa}	0.78 ± 0.20^{Aa}	0.52 ± 0.25^{Ab}
	250 MPa	0.93 ± 0.09^{Ba}	0.58 ± 0.01^{Ab}	0.57 ± 0.10^{Ab}	0.89 ± 0.16^{Aa}	0.92 ± 0.09^{Aa}	0.76 ± 0.06^{Aa}	0.48 ± 0.03^{Bb}	0.55 ± 0.22^{Ab}
	330 MPa	0.83 ± 0.05^{Ba}	0.88 ± 0.09^{Ba}	0.26 ± 0.12^{Bb}	1.00 ± 0.09^{Aa}	0.79 ± 0.07^{Aa}	0.62 ± 0.08^{Ac}	0.25 ± 0.01^{Cb}	0.43 ± 0.20^{Ab}

All values are the mean ± standard deviation (n = 3). Different letters (^{A,B,C}) in the same column indicate significant differences (p<0.05). Different letters (^{a,b,c,d}) in the same line indicate significant differences (p<0.05).

Please cite this article as: Erkan, N., et al., The effect of different high pressure conditions on the quality and shelf life of cold smoked fish, *Innovative Food Science and Emerging Technologies* (2011), doi:10.1016/j.ifset.2010.12.004

Table 4
Amino acid composition of untreated and HP-treated cold smoked salmon (*insignificant data compared to control are shown with dark colour).

Amino acid	C	220 MPa, 3 °C for 5 min	220 MPa, 3 °C for 10 min	250 MPa, 3 °C for 5 min	250 MPa, 3 °C for 10 min	330 MPa, 3 °C for 5 min	330 MPa, 3 °C for 10 min	220 MPa, 7 °C for 5 min	220 MPa, 7 °C for 10 min	250 MPa, 7 °C for 5 min	250 MPa, 7 °C for 10 min	330 MPa, 7 °C for 5 min	330 MPa, 7 °C for 10 min
Lys	2093 ± 5.42	1021 ± 9.94	1724 ± 14.41	879 ± 0.22	591 ± 3.79	2134 ± 10.12	668 ± 6.42	947 ± 10.49	2333 ± 37.52	1365 ± 9.14	783 ± 7.22	2312 ± 13.58	1412 ± 5.28
Meth	646 ± 2.65	437 ± 10.10	611 ± 5.28	310 ± 1.93	234 ± 0.37	776 ± 0.96	275 ± 0.68	371 ± 0.03	834 ± 2.749	511 ± 2.15	287 ± 0.86	806 ± 1.71	557 ± 1.72
Thre	751 ± 20.09	403 ± 7.88	**771* ± 1.97**	364 ± 0.53	259 ± 2.78	1015 ± 0.41	280 ± 2.03	417 ± 3.17	1004 ± 8.29	552 ± 1.77	349 ± 5.26	1029 ± 10.56	601 ± 0.46
Isoleu	1100 ± 4.67	569 ± 11.28	961 ± 4.12	483 ± 2.08	329 ± 0.06	1208 ± 12.33	379 ± 2.05	508 ± 6.72	1283 ± 15.45	812 ± 0.28	451 ± 2.67	1243 ± 0.53	795 ± 3.45
Leu	1530 ± 1.19	780 ± 5.91	1374 ± 35.87	697 ± 6.08	470 ± 1.07	1741 ± 44.78	508 ± 2.17	755 ± 9.07	1860 ± 12.703	1128 ± 2.11	626 ± 0.66	1826 ± 0.99	1151 ± 6.50
Phen	758 ± 4.08	441 ± 5.54	797 ± 1.213	341 ± 1.56	281 ± 2.13	1028 ± 35.54	305 ± 0.35	429 ± 1.06	1075 ± 15.733	625 ± 2.07	396 ± 0.82	1054 ± 0.39	655 ± 5.81
Val	1322 ± 5.32	642 ± 2.73	1071 ± 5.73	579 ± 1.84	396 ± 2.25	1371 ± 1.32	437 ± 1.15	575 ± 15.30	1463 ± 20.63	973 ± 0.94	509 ± 0.55	1391 ± 10.48	901 ± 8.51
His	476 ± 0.91	278 ± 0.52	586 ± 2.38	217 ± 2.04	180 ± 1.00	752 ± 14.07	187 ± 0.09	297 ± 2.495	717 ± 2.78	397 ± 2.29	255 ± 1.24	729 ± 12.73	465 ± 4.08
Ser	666 ± 7.23	426 ± 5.01	699 ± 6.12	399 ± 1.94	297 ± 3.24	1036 ± 5.87	335 ± 1.92	409 ± 3.61	928 ± 0.85	519 ± 6.09	423 ± 3.42	971 ± 2.70	588 ± 8.94
Arg	1126 ± 3.61	614 ± 0.41	1180 ± 9.58	499 ± 6.95	405 ± 0.69	1450 ± 48.91	446 ± 8.67	634 ± 4.48	1592 ± 0.32	870 ± 7.93	518 ± 5.875	1614 ± 1.40	992 ± 7.59
Cys	137 ± 0.85	450 ± 3.81	191 ± 0.97	94 ± 1.09	199 ± 1.80	399 ± 2.78	211 ± 2.42	244 ± 2.53	307 ± 2.97	144 ± 0.79	228 ± 4.00	226 ± 2.02	217 ± 2.45
Tyr	563 ± 2.36	**581* ± 30.61**	716 ± 4.51	270 ± 3.43	310 ± 0.73	913 ± 3.51	335 ± 3.12	453 ± 1.12	1043 ± 7.15	462 ± 1.03	390 ± 7.06	946 ± 13.18	657 ± 13.16
Ala	1048 ± 9.54	1172 ± 2.04	683 ± 5.52	382 ± 27.91	591 ± 9.33	909 ± 1.15	891 ± 0.39	**1077* ± 22.09**	**1046* ± 11.61**	631 ± 3.80	707 ± 1.15	1742 ± 26.15	984 ± 9.42
Asp	2042 ± 5.41	1001 ± 5.27	1885 ± 20.24	511 ± 4.92	615 ± 7.72	2385 ± 42.68	639 ± 1.36	989 ± 11.36	2396 ± 41.13	1084 ± 0.27	818 ± 8.04	2486 ± 10.98	1458 ± 10.36
Glut	2795 ± 49.11	1252 ± 4.98	2407 ± 20.24	903 ± 9.18	810 ± 0.39	3084 ± 10.80	822 ± 0.76	1321 ± 15.37	3116 ± 4.90	1865 ± 0.36	1037 ± 7.29	3340 ± 7.2	1948 ± 1.69
Gly	830 ± 2.38	473 ± 3.89	846 ± 4.97	393 ± 1.96	329 ± 3.69	1118 ± 7.51	351 ± 1.32	482 ± 9.68	1148 ± 5.98	670 ± 0.91	442 ± 3.25	1162 ± 1.59	712 ± 2.23
Prol	593 ± 0.53	279 ± 4.22	**577* ± 6.32**	257 ± 2.61	212 ± 5.41	714 ± 2.21	210 ± 0.50	265 ± 2.631	709 ± 3.39	455 ± 7.36	264 ± 2.39	730 ± 9.99	419 ± 3.02

Table 4 (*continued*)

Amino acid	220 MPa, 15 °C for 5 min	220 MPa, 15 °C for 10 min	250 MPa, 15 °C for 5 min	250 MPa, 15 °C for 10 min	330 MPa, 15 °C for 5 min	330 MPa, 15 °C for 10 min	220 MPa, 25 °C for 5 min	220 MPa, 25 °C for 10 min	250 MPa, 25 °C for 5 min	250 MPa, 25 °C for 10 min	330 MPa, 25 °C for 5 min	330 MPa, 25 °C for 10 min
Lys	665 ± 2.82	1514 ± 7.34	973 ± 1.94	2194 ± 7.29	1813 ± 3.95	911 ± 6.41	3644 ± 6.48	1304 ± 0.44	2208 ± 15.25	2650 ± 14.04	2460 ± 0.00	3712 ± 4.94
Meth	249 ± 2.27	571 ± 1.22	391 ± 2.10	825 ± 2.71	798 ± 4.04	292 ± 2.82	1123 ± 3.22	500 ± 3.35	832 ± 0.60	879 ± 3.99	951 ± 0.00	1170 ± 6.69
Thre	280 ± 7.16	654 ± 3.61	387 ± 0.94	958 ± 1.47	901 ± 5.96	314 ± 1.55	1307 ± 8.52	530 ± 2.86	972 ± 3.49	1013 ± 4.23	1070 ± 0.01	1344 ± 1.17
Isoleu	369 ± 4.16	836 ± 1.43	538 ± 3.22	1235 ± 12.10	**1118* ± 8.60**	478 ± 4.53	1915 ± 1.93	699 ± 0.35	1174 ± 3.35	1490 ± 3.88	1382 ± 02	2051 ± 2.78
Leu	532 ± 0.48	1219 ± 9.70	797 ± 0.02	1790 ± 16.08	1626 ± 17.34	681 ± 10.21	2634 ± 4.56	1038 ± 3.86	1769 ± 25.49	2058 ± 9.18	2003 ± 0.01	2824 ± 5.78
Phen	319 ± 15.22	700 ± 1.64	458 ± 4.19	1023 ± 7.89	976 ± 5.15	327 ± 4.40	1332 ± 1.00	584 ± 0.46	1008 ± 4.26	1070 ± 1.20	1143 ± 0.01	1460 ± 2.56
Val	426 ± 1.79	961 ± 0.71	618 ± 10.73	1383 ± 6.82	1266 ± 12.52	584 ± 5.74	2236 ± 2.31	810 ± 0.09	**1310* ± 15.03**	1760 ± 10.96	1582 ± 0.01	2412 ± 1.35
His	200 ± 5.90	**478* ± 1.98**	276 ± 2.08	715 ± 17.11	703 ± 2.19	206 ± 0.70	853 ± 5.56	396 ± 0.79	701 ± 0.76	679 ± 1.47	832 ± 0.01	864 ± 1.33
Ser	304 ± 4.27	583 ± 2.72	410 ± 0.84	851 ± 6.32	1021 ± 0.57	294 ± 5.01	1669 ± 20.49	510 ± 2.19	920 ± 13.63	975 ± 4.92	929 ± 0.02	1102 ± 1.99
Arg	420 ± 4.77	**1048* ± 14.56**	636 ± 4.35	1553 ± 8.64	1397 ± 16.90	471 ± 0.86	2069 ± 3.86	901 ± 19.78	1491 ± 7.09	1733 ± 11.57	1734 ± 0.00	2200 ± 10.40
Cys	173 ± 1.35	335 ± 12.34	179 ± 0.31	309 ± 6.79	251 ± 10.73	95 ± 2.59	115 ± 1.31	273 ± 0.95	310 ± 5.22	161 ± 2.47	271 ± 0.00	117 ± 3.04
Tyr	323 ± 4.04	681 ± 5.47	455 ± 5.09	908 ± 14.42	920 ± 1.59	254 ± 1.81	925 ± 5.64	**588* ± 12.56**	923 ± 8.73	680.267 ± 4.07	1039 ± 0.00	955 ± 7.40
Ala	729 ± 8.72	910 ± 3.39	925 ± 0.34	913 ± 25.82	830 ± 7.28	508 ± 0.70	2248 ± 6.24	**1072* ± 10.83**	876 ± 8.97	1973 ± 5.429	1075 ± 0.00	2398 ± 23.86
Asp	700 ± 12.33	1581 ± 20.13	948 ± 0.064	2272 ± 23.73	1859 ± 7.57	582 ± 11.23	2536 ± 20.46	1291 ± 11.03	2294 ± 6.04	1931 ± 1.79	2511 ± 0.01	3198 ± 20.452
Glut	924 ± 12.96	2083 ± 31.61	1243 ± 1.88	3088 ± 14.34	2523 ± 17.28	1174 ± 10.59	4029 ± 67.64	1684 ± 0.68	3041 ± 1.56	3455 ± 27.33	3381 ± 0.01	5074 ± 9.77
Gly	342 ± 0.914	796 ± 7.17	451 ± 2.81	1128 ± 2.58	1174 ± 6.82	353 ± 0.98	1481 ± 4.93	658 ± 2.96	1075 ± 0.74	1588 ± 6.88	1248 ± 0.01	1658 ± 3.668
Prol	210 ± 0.21	483 ± 14.71	270 ± 3.29	674 ± 3.02	631 ± 7.71	230 ± 1.75	1053 ± 0.49	417 ± 10.81	689 ± 1.05	988 ± 6.16	755 ± 0.00	1166 ± 4.62

Table 5
Sensory changes of unpressurized and pressurized cold smoked salmon stored at 2 °C.

Storage weeks		0	1	2	3	4	5	6	7	8
Appearance	Control	8.80 ± 0.05^{Aa}	8.67 ± 0.47^{Aa}	7.67 ± 0.47^{Ab}	7.50 ± 0.41^{Ab}	7.33 ± 0.47^{Ab}	6.00 ± 0.41^{Ac}	5.67 ± 0.48^{Ac}	4.50 ± 0.41^{Ad}	4.00 ± 0.82^{Ad}
	250 MPa/3 °C/5 min	8.85 ± 0.16^{Aa}	8.40 ± 0.65^{Ab}	8.40 ± 0.29^{Bb}	8.00 ± 0.41^{Bb}	7.50 ± 1.08^{Bc}	6.83 ± 0.62^{Bd}	6.27 ± 0.21^{Bd}	5.67 ± 0.24^{Be}	4.83 ± 0.47^{Bf}
	250 MPa/25 °C/10 min	8.87 ± 0.17^{Aa}	8.73 ± 0.21^{Aa}	7.63 ± 1.16^{Aa}	7.50 ± 0.41^{Aa}	7.27 ± 0.95^{Ab}	6.93 ± 0.33^{Bb}	6.17 ± 0.47^{Bc}	6.00 ± 0.71^{Bd}	5.17 ± 0.24^{Be}
Odour	Control	8.77 ± 0.02^{Aa}	8.67 ± 0.24^{Aa}	7.73 ± 0.52^{Ab}	7.50 ± 0.41^{Ab}	7.57 ± 0.84^{Ab}	6.00 ± 0.41^{Ac}	5.83 ± 0.62^{Ac}	4.70 ± 0.22^{Ad}	4.33 ± 0.94^{Ae}
	250 MPa/3 °C/5 min	8.97 ± 0.03^{Aa}	7.80 ± 1.30^{Ba}	7.71 ± 0.85^{Aa}	7.53 ± 0.41^{Aa}	7.83 ± 0.53^{Ba}	6.20 ± 0.51^{Bb}	6.13 ± 0.19^{Bb}	5.40 ± 0.43^{Bc}	5.33 ± 0.47^{Bc}
	250 MPa/25 °C/10 min	8.87 ± 0.02^{Aa}	8.67 ± 0.47^{Aa}	7.93 ± 0.66^{Ab}	7.50 ± 0.61^{Bb}	7.27 ± 0.41^{Ab}	6.70 ± 0.47^{Bc}	6.43 ± 0.33^{Bc}	5.67 ± 0.24^{Bd}	5.50 ± 0.41^{Bd}
Flavour	Control	9.61 ± 0.01^{Aa}	8.63 ± 0.26^{Aa}	8.13 ± 0.19^{Aa}	7.17 ± 0.62^{Aa}	7.50 ± 0.81^{Aa}	6.10 ± 0.37^{Ab}	5.83 ± 0.62^{Ab}	4.33 ± 0.47^{Ac}	4.00 ± 0.81^{Ac}
	250 MPa/3 °C/5 min	9.78 ± 0.04^{Aa}	8.53 ± 1.23^{Aa}	8.03 ± 0.44^{Aa}	7.37 ± 0.58^{Aa}	7.43 ± 0.66^{Aa}	6.40 ± 0.43^{Bb}	6.13 ± 0.18^{Bb}	5.53 ± 0.47^{Bb}	5.33 ± 0.45^{Bc}
	250 MPa/25 °C/10 min	9.67 ± 0.08^{Aa}	9.17 ± 0.62^{Ab}	8.00 ± 0.40^{Aa}	7.27 ± 0.21^{Ab}	7.46 ± 1.05^{Aa}	6.83 ± 0.46^{Bb}	6.10 ± 0.50^{Bb}	5.67 ± 0.24^{Bc}	5.33 ± 0.24^{Bc}
Texture	Control	8.97 ± 0.17^{Aa}	8.93 ± 0.49^{Aa}	7.60 ± 0.78^{Aa}	7.60 ± 0.24^{Aa}	6.93 ± 0.82^{Aa}	6.33 ± 0.62^{Aa}	6.00 ± 0.41^{Ab}	5.00 ± 0.10^{Ac}	4.33 ± 0.62^{Ad}
	250 MPa/3 °C/5 min	8.80 ± 0.07^{Aa}	8.17 ± 0.62^{Ba}	7.60 ± 1.13^{Aa}	7.50 ± 0.41^{Aa}	7.30 ± 0.47^{Ba}	6.40 ± 0.20^{Bb}	6.00 ± 0.41^{Ab}	5.23 ± 0.21^{Bc}	4.83 ± 0.24^{Bc}
	250 MPa/25 °C/10 min	8.78 ± 0.27^{Aa}	8.83 ± 0.24^{Aa}	7.83 ± 0.94^{Aa}	7.60 ± 0.65^{Aa}	6.90 ± 0.64^{Aa}	6.43 ± 0.42^{Bb}	6.23 ± 0.52^{Bb}	5.43 ± 0.09^{Bc}	5.33 ± 0.24^{Cc}
Overall quality	Control	Very good	Very good	Good	Good	Good	Sufficient	Sufficient	Unacceptable	Unacceptable
	250 MPa/3 °C/5 min	Very good	Very good	Very good	Good	Good	Sufficient	Sufficient	Sufficient	Sufficient
	250 MPa/25 °C/10 min	Very good	Very good	Good	Good	Good	Sufficient	Sufficient	Sufficient	Sufficient

All values are the mean ± standard deviation ($n = 3$). Different letters (^{A,B,C}) in the same column indicate significant differences ($p < 0.05$). Different letters (^{a,b,c,d,e,f}) in the same line indicate significant differences ($p < 0.05$).

depending on the treatment combination and there was no clear trend as to how the pressure level, hold time or temperature interacted to affect values.

Other work has shown that minimal colour changes occur when cold smoked salmon was pressure-treated with 100 MPa at 30 °C for 10 min (Lakshmanan et al., 2005). However, cold smoked salmon muscle was reported to display appreciable differences when treated with 400 MPa at 20 °C for 15 min (Gómez-Estace et al., 2007).

Lipid oxidation was studied using the TBA value to monitor levels of secondary oxidation products formed. TBA values a variety of secondary products, but mainly MDA. This method has been found to agree well with rancidity development in seafood based systems when compared to sensory analysis (Erkan & Özden, 2008). The TBA values for untreated and pressue-treated cold smoked salmon are shown in Table 3. TBA values for HP treatments at 3 °C/5 min, 15 °C/5 min, 15 °C/10 min and 25 °C/10 min did not differ significantly from controls, irrespective of pressure level. Other treatment conditions gave significantly higher TBA values. In the literature, the TBA values of HP treated fish and fish products with increasing pressure and pressure-holding times have been reported to show progressive changes (Sequeira-Munoz, Chevalier, LeBail, Ramaswamy, & Simpson, 2006). Lakshmanan et al. (2005) reported favourable changes in TBA levels in cold smoked salmon treated at 100 MPa, 20 °C for 30 min, at 100 MPa, 30 °C for 10 min, at 100 MPa, 30 °C for 30 min, at 300 MPa, 20 °C for 10 min and at 300 MPa, 20 °C for 30 min. Gómez-Estace et al. (2007) reported that 300 MPa pressure 20 °C temperature 15 min time had little effect on lipid oxidation of cold smoked muscle while 200 and 400 MPa, 20 °C for 15 min had significant effect on lipid oxidation.

Chemical analysis such as trimethylamine nitrogen (TMA-N) is widely used in determining the quality of seafood products. The formation of TMA from the reduction of trimethylamine oxide (TMAO) is caused by bacterial degradation and enzymatic activity (Ludorff & Meyer, 1973; Wu & Bechtel, 2008), but the effect of high-pressure treatment on the stability of TMA is not known. TMA-N content of unpressurized and pressurized cold smoked salmon is shown in Table 2. The TMA-N values obtained at 220 MPa/7 °C/5 min, 330 MPa/7 °C/5 min and 250 MPa/25 °C/5 min were lower than the controls. Otherwise, all the other treatment combinations gave similar or higher values than controls.

Free amino acids are natural components of fish and fish products and they play important roles in maintaining seafood quality and determining nutritive value. The concentration of these constituents in sea foods has been of interest because of their important influence on the organoleptic properties (Belitz & Grosch, 1999). HP-treated cold smoked salmon fillets showed significant changes in free amino acid content ($p < 0.05$) relative to untreated cold smoked salmon fillets (Table 4). The cause of these changes is protein denaturation. Denaturation of food proteins has been reported after HP treatment (Sendra, Saldo, Capellas, & Guamis, 2000). Reflection of the changes in amino acids is more pronounced in raw sea food. Cooked images of HP-treated raw fish are associated with changes of free amino acid content after HP treatment (Erkan, Üretener, Alpas, Selcuk, et al., 2010). In our study, the amino acid changes of smoking fish are associated with changes in colour of smoked fishes.

3.1. Shelf-life studies on pressure treated cold-smoked salmon

Two treatment combinations, based on the results from the initial study, were selected for more detailed shelf-life assessment. Changes in the sensory, physicochemical and microbiological quality of cold smoked salmons HP-treated at 250 MPa, 3 °C for 5 min, at 250 MPa, 25 °C for 10 min and stored at 2 °C for 8 weeks were investigated.

Two treatment combinations (250 MPa, 3 °C, 5 min and 250 MPa, 25 °C, 10 min) were selected for a shelf-life study where the cold smoked salmon was stored at 2 °C for 8 weeks. These treatments were selected based on the results of the initial study (caused least

Table 6
Colour changes of unpressurized and pressurized cold smoked salmon stored at 2 °C.

Storage weeks		0	1	2	3	4	5	6	7	8
L*	Control	36.17 ± 3.1^{Aa}	39.9 ± 3.9^{Aa}	40.7 ± 2.9^{Aa}	42.6 ± 2.7^{Ab}	40.9 ± 2.0^{Aa}	42.8 ± 2.3^{Ab}	47.0 ± 3.5^{Ac}	44.3 ± 3.2^{Abc}	44.8 ± 3.1^{Abc}
	250 MPa/3 °C/5 min	38.17 ± 4.0^{Aa}	44.0 ± 2.1^{Ba}	47.4 ± 2.4^{Bb}	42.1 ± 2.0^{Aa}	43.4 ± 1.9^{Aa}	45.3 ± 1.7^{Aa}	49.5 ± 3.6^{Ab}	46.8 ± 2.3^{Ab}	46.7 ± 3.2^{Ab}
	250 MPa/25 °C/10 min	36.17 ± 2.1^{Aa}	46.8 ± 2.2^{Bb}	43.5 ± 1.4^{Ab}	42.0 ± 3.2^{Ab}	43.4 ± 4.5^{Ab}	46.9 ± 5.5^{Ab}	53.4 ± 0.8^{Bc}	47.5 ± 1.9^{Ab}	47.5 ± 3.9^{Ab}
a*	Control	16.17 ± 2.2^{Aa}	18.9 ± 3.3^{Aa}	17.8 ± 1.5^{Aa}	20.7 ± 2.8^{Aa}	17.7 ± 0.6^{Aa}	19.0 ± 2.2^{Aa}	23.2 ± 3.4^{Aa}	17.5 ± 2.7^{Aa}	18.6 ± 1.7^{Aa}
	250 MPa/3 °C/5 min	19.18 ± 1.1^{Aa}	20.3 ± 3.4^{Aa}	22.5 ± 3.4^{Aa}	22.4 ± 0.8^{Aa}	20.9 ± 1.3^{Ba}	21.4 ± 1.2^{Aa}	23.2 ± 2.6^{Aa}	20.1 ± 1.3^{Aa}	18.2 ± 1.2^{Aa}
	250 MPa/25 °C/10 min	19.37 ± 1.9^{Aa}	24.5 ± 1.6^{Ab}	20.9 ± 2.8^{Aa}	19.9 ± 3.1^{Aab}	22.2 ± 2.3^{Bab}	22.0 ± 2.2^{Aab}	29.7 ± 1.5^{Bc}	20.8 ± 3.3^{Aa}	17.8 ± 3.2^{Aa}
b*	Control	24.17 ± 3.0^{Aa}	22.5 ± 5.0^{Ab}	22.3 ± 3.9^{Aa}	24.8 ± 4.0^{Aa}	21.9 ± 2.9^{Aab}	23.2 ± 2.3^{Aa}	33.3 ± 3.1^{Ac}	25.8 ± 4.9^{Abc}	27.1 ± 3.3^{Aac}
	250 MPa/3 °C/5 min	20.37 ± 2.5^{Aa}	25.6 ± 1.3^{Ab}	30.1 ± 1.8^{Bc}	24.8 ± 2.3^{Ab}	24.8 ± 0.5^{Ab}	27.4 ± 2.6^{Bb}	33.7 ± 3.5^{Ac}	27.6 ± 3.6^{Abc}	26.6 ± 3.4^{Abc}
	250 MPa/25 °C/10 min	21.37 ± 3.1^{Aa}	27.4 ± 2.0^{Ab}	25.3 ± 2.2^{Aab}	22.6 ± 3.4^{Aab}	27.8 ± 2.1^{Bb}	29.2 ± 1.2^{Bb}	43.8 ± 1.6^{Bc}	28.2 ± 1.7^{Ab}	28.7 ± 1.1^{Ab}
ΔE	Control	3.77 ± 2.1^{Aa}	5.7 ± 3.7^{Aa}	4.3 ± 2.3^{Aa}	3.0 ± 1.1^{Aa}	3.2 ± 1.1^{Aa}	5.2 ± 1.3^{Aa}	7.8 ± 3.7^{Ab}	5.6 ± 2.5^{Aa}	4.3 ± 1.6^{Aa}
	250 MPa/3 °C/5 min	3.92 ± 3.1^{Aa}	8.3 ± 3.3^{Ba}	12.2 ± 4.2^{Bb}	3.3 ± 4.2^{Aa}	5.4 ± 1.0^{Ba}	5.4 ± 2.2^{Aa}	8.5 ± 3.1^{Aa}	5.4 ± 2.0^{Aa}	4.6 ± 1.9^{Aa}
	250 MPa/25 °C/10 min	4.17 ± 4.0^{Aa}	10.8 ± 3.4^{Ba}	7.3 ± 4.2^{Ca}	5.4 ± 4.2^{Ba}	9.2 ± 2.1^{Ca}	8.3 ± 2.0^{Ba}	14.0 ± 1.8^{Ba}	6.6 ± 3.0^{Aa}	6.4 ± 4.1^{Aa}

All values are the mean ± standard deviation (n = 3). Different letters (^{A,B,C}) in the same column indicate significant differences ($p<0.05$). Different letters (^{a,b,c}) in the same line indicate significant differences ($p<0.05$).

chemical changes) and informal observations on colour changes resulting from the different pressure treatments.

The storage life of smoked fish is affected by the initial microbial load of the fish, micro flora, packaging material, production method, size and composition of initial numbers of freezing and thawing cycles and quality of raw material, storage temperature and packing methods (Dondero et al., 2004). Other researchers have reported that vacuum-packaged cold smoked salmon could not be accepted after 32 and 49 days at 5 °C (Truelstrup, Drewes, & Huss, 1998; Leroi, Joffraud, Chevalier, & Cardinal, 1998). Smoked fish demonstrated a shelf life of 6 and 8 weeks for untreated and HP treated samples stored in cold storage conditions, respectively, according to sensory criterion (Table 5). Gómez-Estace et al. (2007) reported that the shelf life of cold smoked dolphinfish was 65 days and this was not affected by a pressure treatment of 300 MPa/20 °C/15 min. Lakshmanan et al. (2005) reported the limit of acceptability for pressurized cold smoked salmon (200 MPa, 20 °C for 20 min) in refrigerated storage to be 6 weeks.

L* value of HP treatment samples was increased after 6 weeks and lightness was quite stable ($p>0.05$) in pressurized and unpressurized samples after 6 weeks of storage. a* and b* values of the untreated and treated first group (250 MPa/3 °C/5 min) samples did not change while treated second group (250 MPa/25 °C/10 min) increased during storage (Table 6). Lakshmanan et al. (2005) found that there was a slight increase in the redness and yellowness values during storage (at 5 °C) of pressurized (100, 200 and 300 MPa) and unpressurized cold-smoked salmon. Gómez-Estace et al. (2007) reported stable colour in the sample pressurized at 300 MPa, 20 °C for 15 min during chilled storage.

During storage, the pH values increased gradually in untreated samples, whereas in HP treated samples the values decreased initially and then increased (Table 7). Increases in pH indicate the accumulation of alkaline compounds, such as ammonium compounds and TMA, mainly derived from microbial action (Ludorff & Meyer, 1973). A reduction in pH values might be attributable to the inhibition of bacteria growth by HP treatment in the fish muscle. The post mortem metabolism of nitrogenous compounds is mainly responsible for the gradual loss of fish quality. The chemical spoilage of fish samples during storage was usually evaluated by measuring the changes in the content of TVB-N and TMA (Tülsner, 1994). At week 8, the TVB-N levels in the untreated samples exceeded the acceptable level 30 mg/100 g of flesh suggested for fish (Ludorff & Meyer, 1973). However, the TVB-N content of the HP-treated samples (Table 7) remained below the acceptable level (30 mg/100 g) during the 8 weeks of storage. In the present study, TMA-N values in untreated and HP treated samples were significantly lower than the general TMA-N limit for fish (5 mg/100 g) (Erkan & Özden, 2008) throughout the storage period. Similar results were found by Leroi et al. (1998). The TBA value of untreated and HP treated samples increased to a maximum during storage up to the 4th week and decreased (Table 7). The decrease in TBA values after week 4 of storage may represent the breakdown of the malonaldehyde to tertiary degradation. Similar results have been obtained in pressurized smoked dolphinfish (Gómez-Estace et al., 2007).

The low initial TPC and TVC's (<3 log cfu/g) indicate very good fish quality. In untreated samples TPC and TVC's exceeded the value of 6 log cfu/g, considered as the upper acceptability limit for marine species (Erkan, 2007), on 5 and 8 storage weeks at 2 °C (Table 8). On the other hand, in HP treated samples TPC and TVC's did not reach these values throughout the storage period. Compared with the control, all treatments significantly inhibited the growth of TPC and TVC's in cold smoked salmon samples during the storage period. Similar results have been reported by He, Adams, Farkas, and Morrissey (2002) and Gómez-Estace et al. (2007).

Table 7
Change of pH, TVB-N, TMA and TBA values of the unpressurized and pressurized cold smoked salmon stored at 2 °C.

Storage weeks		0	1	2	3	4	5	6	7	8
pH	Control	6.17 ± 0.1^{Aa}	6.19 ± 0.3^{Aa}	6.16 ± 0.3^{Aa}	5.96 ± 0.1^{Aa}	5.69 ± 0.5^{Ab}	5.85 ± 0.2^{Ab}	6.11 ± 0.1^{Aa}	6.0 ± 0.2^{Aa}	6.73 ± 0.1^{Ac}
	250 MPa, 3 °C, 5 min	6.15 ± 0.1^{Aa}	6.18 ± 0.2^{Aa}	6.07 ± 0.4^{Bb}	5.93 ± 0.2^{Ab}	5.93 ± 0.5^{Bb}	5.95 ± 0.1^{Ab}	5.7 ± 0.1^{Bb}	6.07 ± 0.0^{Ab}	6.15 ± 0.4^{Bb}
	250 MPa, 25 °C, 10 min	6.16 ± 0.1^{Aa}	6.14 ± 0.1^{Ba}	6.08 ± 0.0^{Ba}	5.95 ± 0.1^{Ab}	5.79 ± 0.3^{Cb}	5.9 ± 0.1^{Ab}	5.86 ± 0.1^{Bb}	6.17 ± 0.1^{Ba}	6.17 ± 0.4^{Ba}
TVB-N (mg/100 g)	Control	16.07 ± 0.2^{Aa}	17.5 ± 0.2^{Aa}	16.3 ± 0.0^{Ab}	19.9 ± 1.2^{Ac}	15.6 ± 0.1^{Ad}	19.9 ± 2.0^{Ac}	18.7 ± 0.9^{Ac}	19.2 ± 1.6^{Ac}	31.7 ± 1.3^{Ae}
	250 MPa, 3 °C, 5 min	15.17 ± 0.1^{Aa}	17.5 ± 0.2^{Aa}	14.7 ± 1.1^{Bb}	17.6 ± 0.7^{Ba}	14.7 ± 0.4^{Bb}	20.4 ± 0.6^{Ac}	20.0 ± 0.3^{Bc}	20.6 ± 0.1^{Bc}	20.0 ± 0.6^{Bc}
	250 MPa, 25 °C, 10 min	16.37 ± 0.3^{Aa}	18.2 ± 1.0^{Ba}	20.1 ± 0.9^{Ca}	18.9 ± 1.6^{Ca}	15.5 ± 0.2^{Ab}	20.1 ± 0.3^{Aa}	21.6 ± 0.0^{Bc}	22.2 ± 1.1^{Cc}	20.6 ± 1.0^{Ba}
TMA-N (mg/100 g)	Control	0.70 ± 0.1^{Aa}	0.8 ± 0.0^{Aa}	0.9 ± 0.0^{Ab}	0.8 ± 0.0^{Aa}	0.9 ± 0.0^{Aa}	0.9 ± 0.0^{Ab}	0.9 ± 0.0^{Ab}	1.0 ± 0.0^{Ac}	1.0 ± 0.1^{Ac}
	250 MPa, 3 °C, 5 min	0.71 ± 0.1^{Aa}	0.8 ± 0.0^{Aa}	0.8 ± 0.0^{Aa}	0.8 ± 0.0^{Aa}	0.9 ± 0.0^{Ab}	0.9 ± 0.0^{Ab}	0.9 ± 0.0^{Ab}	1.0 ± 0.0^{Ac}	0.9 ± 0.0^{Ab}
	250 MPa, 25 °C, 10 min	0.70 ± 0.1^{Aa}	0.8 ± 0.0^{Aa}	0.9 ± 0.0^{Ab}	0.9 ± 0.0^{Ab}	0.9 ± 0.0^{Ab}	0.9 ± 0.0^{Ab}	0.9 ± 0.0^{Ab}	1.0 ± 0.0^{Ac}	0.9 ± 0.0^{Ab}
TBA (mg MDA/kg meat)	Control	1.17 ± 0.1^{Aa}	1.5 ± 0.2^{Aa}	0.7 ± 0.0^{Ab}	0.8 ± 0.0^{Ab}	1.0 ± 0.1^{Ac}	0.8 ± 0.0^{Ac}	0.1 ± 0.0^{Ad}	0.1 ± 0.0^{Ad}	0.2 ± 0.1^{Ad}
	250 MPa, 3 °C, 5 min	1.20 ± 0.2^{Aa}	1.3 ± 0.1^{Ba}	0.6 ± 0.0^{Ab}	0.7 ± 0.0^{Ab}	0.8 ± 0.1^{Ac}	0.8 ± 0.0^{Ac}	0.1 ± 0.0^{Ad}	0.1 ± 0.0^{Ad}	0.1 ± 0.0^{Ad}
	250 MPa, 25 °C, 10 min	1.18 ± 0.1^{Aa}	1.6 ± 0.0^{Aa}	0.7 ± 0.0^{Ab}	0.7 ± 0.1^{Ab}	0.9 ± 0.0^{Ac}	0.7 ± 0.0^{Ab}	0.1 ± 0.0^{Ad}	0.1 ± 0.0^{Ad}	0.2 ± 0.0^{Ad}

All values are the mean ± standard deviation (n = 3). Different letters (^{A,B,C}) in the same column indicate significant differences ($p<0.05$). Different letters (^{a,b,c,d,e}) in the same line indicate significant differences ($p<0.05$).

Please cite this article as: Erkan, N., et al., The effect of different high pressure conditions on the quality and shelf life of cold smoked fish, *Innovative Food Science and Emerging Technologies* (2011), doi:10.1016/j.ifset.2010.12.004

Table 8
Change of microbial load of unpressurized and pressurized cold smoked salmon stored at 2 °C.

Storage weeks		0	1	2	3	4	5	6	7	8
PVC (log cfu/g)	Control	$<3^{Aa}$	$<3^{Aa}$	$<3^{Aa}$	3^{Aa}	4.20^{Ab}	6.29^{Ac}	6.65^{Ad}	6.00^{Ae}	5.89^{Ae}
	250 MPa/3 °C/5 min	$<3^{Aa}$	$<3^{Aa}$	$<3^{Aa}$	$<3^{Aa}$	$<3^{Ba}$	$<3^{Ba}$	$<3^{Ba}$	$<3^{Ba}$	$<3^{Ba}$
	250 MPa/25 °C/10 min	$<3^{Aa}$	$<3^{Aa}$	$<3^{Aa}$	$<3^{Aa}$	$<3^{B}$	$<3^{Ba}$	$<3^{Ba}$	$<3^{Ba}$	$<3^{Ba}$
TVC (log cfu/g)	Control	$<3^{Aa}$	$<3^{Aa}$	$<3^{Aa}$	$<3^{Aa}$	3.80^{Ab}	4.63^{Ac}	4.84^{Ad}	5.50^{Ae}	5.90^{Af}
	250 MPa/3 °C/5 min	$<3^{Aa}$	$<3^{Aa}$	$<3^{Aa}$	$<3^{Aa}$	$<3^{Ba}$	$<3^{Ba}$	$<3^{Ba}$	3^{Bb}	3.95^{Bc}
	250 MPa/25 °C/10 min	$<3^{Aa}$	$<3^{Aa}$	$<3^{Aa}$	$<3^{Aa}$	$<3^{Ba}$	$<3^{Ba}$	$<3^{Ba}$	3.17^{Bb}	4.11^{Bc}

Different letters (^{A,B}) in the same column indicate significant differences ($p<0.05$). Different letters (^{a,b,c,d,e,f}) in the same line indicate significant differences ($p<0.05$).

4. Conclusions

Different high pressure conditions (at 220–250–330 MPa, 3–7–15–25 °C for 5–10 min) were tested to establish the best processing conditions for cold smoked fish fillets of salmon. The best quality scores were achieved for cold smoked salmon pressurized at 220–250 MPa, 3 °C for 5 min, at 330 MPa, 15 °C for 5 min and at 250 MPa, 25 °C for 10 min. Quality and shelf life criteria assessment of HP treatment cold smoked fish from salmon stored at 2 °C was assessed by sensory, chemical and microbiological methods. The HP treated samples (at 250 MPa, 3 °C for 5 min and at 250 MPa, 25 °C for 10 min) were acceptable up to the 8th week of storage, thus extending the shelf-life by 2 weeks compared to untreated samples.

Acknowledgments

This work was supported by the TUBİTAK-TOVAG projects (No: 108O668) and the Research Found of Istanbul University (Project Number BYP-2861).

References

Amerina, M. A., Pangborn, R. V., & Roessler, E. B. (1965). *Principles of sensory evaluation of food.* New York: Academic Press.
Antonacopoulos, N., & Vyncke, W. (1989). Determination of volatile basic nitrogen in fish. *Zeitschrift für Lebensmittel-Untersuchung und Forschung*, *189*, 309−316.
AOAC (1998). AOAC official method 971.14, trimethylamine nitrogen in seafood colourimetric method. In: Hungerford JM (Chapter ed). Fish and other marine products. In: Cunniff, P. Eds. Official methods of analysis of AOAC international, Chapter 35, p 7.
Baumgart, J. (1986). Lebensmittel tierischer Herkunft, Feinkosterzeugnisse, gefrorene, tiefgefrorene und getrocknete Lebensmittel, Fertiggerichte, hitzekonservierte Lebensmlttel, Speiseeis, Zucker, Kakao, Zuckerwaren, Rohmasscn. In Led Baumgart (Ed.), *Mikrobiologtsche Untersuchung von Lebensmitteln* (pp. 59). Hamburg: Behr's.
Belitz, H. D., & Grosch, W. (1999). *Food chemistry.*Berlin: Springer Verlag3-540-64692-2 xliii + 992 pages.
Dondero, M., Cisternas, F., Carvajal, L., & Simpson, R. (2004). Changes in quality of vacuum-packed cold-smoked salmon (*Salmo salar*) as a function of storage temperature. *Food Chemistry*, *87*, 543−550.
Erkan, N. (2007). Sensory, chemical and microbiological attributes of sea bream (*Sparus aurata*): Effect of washing and ice storage. *International Journal of Food Properties*, *10* (3), 421−434.
Erkan, N., & Özden, Ö. (2008). Quality assessment of whole and gutted sardine (*Sardine pilchardus*) stored in ice. *International Journal of Food Science and Technology*, *43*(9), 1549−1559.
Erkan, N., Selçuk, A., & Özden, Ö. (2010a). Amino acid and vitamin composition of raw and cooked horse mackerel. *Food Analytical Methods*, *3*(3), 269−275.
Erkan, N., & Üretener, G. (2010). The effect of high hydrostatic pressure on the microbiological, chemical and sensory quality of fresh gilthead sea bream (*Sparus aurata*). *European Food Research and Technology*, *230*(4), 533−542.
Erkan, N., Üretener, G., & Alpas, H. (2010b). Effect of high pressure (HP) on the quality and shelf life of red mullet (*Mullus surmelutus*). *Innovative Food Science and Emerging Technologies*, *11*, 259−264.
Erkan, N., Üretener, G., Alpas, H., Selcuk, A., Özden, Ö., & Buzrul, S. (2010c). Effect of high hydrostatic pressure (HHP) treatment on physicochemical properties of horse mackerel (*Trachurus trachurus*). *Food and Bioprocess Technology*, doi:10.1007/s11947-010-0415-4.
Gerdes, D. L., & Santos Valdez, C. (1991). Modified atmosphere packaging of commercial Pacific red snapper (*Sebastes entomelas*, *Sebastes flavidus* or *Sebastes godei*). *Lebensmitteln Wissenschaft und Technology*, *24*, 256−258.
Gómez-Estace, J., Gómez-Guillén, P., & Montero, P. (2007). High pressure effects on the quality and preservation of cold-smoked dolphinfish (*Coryphaena hippurus*) fillets. *Food Chemistry*, *102*, 1250−1259.
He, H., Adams, R. M., Farkas, D. F., & Morrissey, M. T. (2002). Use of high-pressure processing for oyster shucking and shelf-life extension. *Journal of Food Science*, *67* (2), 640−645.
Heinz, V., & Bukow, R. (2010). Food preservation by high pressure. *Journal für Verbraucherschutz und Lebensmittelsicherheit*, *5*, 73−81.
Kolsarıcı, N., & Özkaya, Ö. (1998). Gökkusağı Alabalıgı (*Salmo gairdneri*)'nın Raf Ömrü Üzerine Tütsüleme Yöntemleri ve Depolama Sıcaklığının Etkisi. *Journal of Veterinary and Animal Science*, *22*, 273−284.
Lakshmanan, R., Miskin, D., & Piggot, J. R. (2005). Quality of vacuum packed cold-smoked salmon during refrigerated storage as affected by high-pressure processing. *Journal of the Science of Food and Agriculture*, *85*, 655−661.
Leroi, F., Joffraud, J., Chevalier, F., & Cardinal, M. (1998). Study of the microbial ecology of cold-smoked salmon during storage at 8 °C. *International Journal of Food Microbiology*, *39*, 111−121.
Ludorff, W., & Meyer, V. (1973). *Fische und fischerzeugnisse.* Hamburg, Berlin: Paul Parey Verlag.
Rorvik, L., Yndestad, M., & Skjerve, E. (1991). Growth of *Listeria monocytogenes* in vacuum-packed, smoked salmon, during storage at 4 °C. *International Journal of Food Microbiology*, *14*, 111−118.
Sendra, E., Saldo, J., Capellas, M., & Guamis, B. (2000). Decrease of free amino acids in high-pressure treated cheese. *High Pressure Research*, *19*, 33−36.
Sequeira-Munoz, A., Chevalier, D., LeBail, A., Ramaswamy, H. S., & Simpson, B. K. (2006). Physicochemical changes induced in carp (*Cyprinus carpio*) fillets by high pressure processing at low temperature. *Innovative Food Science and Emerging Technologies*, *7*, 13−18.
Sümbüloğlu, K., & Sümbüloğlu, V. (2002). *Biyoistatistik*. 10. *Baskı, p.275, Hatipoğlu Basım ve Yayım San. Tic. Ltd. Sti. ISBN: 975-7527-12-2. Ankara.*
Thakur, B. R., & Nelson, P. E. (1998). High-pressure processing and preservation of food. *Food Reviews International*, *14*, 427−447.
Truelstrup, L., Drewes, S., & Huss, H. (1998). Microbiological quality and shelf life of cold-smoked salmon from three different processing plants. *Food Microbiology*, *15*, 137−150.
Tülsner, M. (1994). *Fischverarbeitung. Bd.1 – Rohstoffeigenschaften von Fisch und Grundlagen der Verarbeitungsprozesse.* Hamburg: Behr's Verlag3-86022-196-5.
Wu, T. H., & Bechtel, P. J. (2008). Ammonia, dimethylamine, trimethylamine, and trimethylamine oxide from raw and processed fish by-products. *Journal of Aquatic Food Product Technology*, *17*(1), 27−38.
Yuste, J., Capellas, M., Pla, R., Fung, D. Y. C., & Mor-Mur, M. M. (2001). High pressure processing for food safety and preservation: A review. *Journal of Rapid Methods and Automation in Microbiology*, *9*, 1−10.

Please cite this article as: Erkan, N., et al., The effect of different high pressure conditions on the quality and shelf life of cold smoked fish, *Innovative Food Science and Emerging Technologies* (2011), doi:10.1016/j.ifset.2010.12.004